PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

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FOR THE YEAR MDCCCXLVI.

PART I.

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MDCCCXLVI.

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THE Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions*, take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions*, that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgement of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body,

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upon any subject, either of Nature or Art, that comes before them. And therefore the thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

The Meteorological Journal hitherto kept by the Assistant Secretary at the Apartments of the Royal Society, by order of the President and Council, and published in the Philosophical Transactions, has been discontinued. The Government, on the recommendation of the President and Council, has established at the Royal Observatory at Greenwich, under the superintendence of the Astronomer Royal, a Magnetical and Meteorological Observatory, where observations are made on an extended scale, which are regularly published. These, which correspond with the grand scheme of observations now carrying out in different parts of the globe, supersede the necessity of a continuance of the observations made at the Apartments of the Royal Society, which could not be rendered so perfect as was desirable, on account of the imperfections of the locality and the multiplied duties of the observer.

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PHILOSOPHICAL TRANSACTIONS.

I. *Experimental Researches in Electricity.—Nineteenth Series.*
By MICHAEL FARADAY, *Esq., D.C.L. F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Cor. Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, &c. &c.*

Received November 6,—Read November 20, 1845.

§ 26. *On the magnetization of light and the illumination of magnetic lines of force*.*

¶ i. *Action of magnets on light.* ¶ ii. *Action of electric currents on light.* ¶ iii. *General considerations.*

¶ i. *Action of magnets on light.*

2146. I HAVE long held an opinion, almost amounting to conviction, in common I believe with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other

* The title of this paper has, I understand, led many to a misapprehension of its contents, and I therefore take the liberty of appending this explanatory note. Neither accepting nor rejecting the hypothesis of an ether, or the corpuscular, or any other view that may be entertained of the nature of light; and, as far as I can see, nothing being really known of a ray of light more than of a line of magnetic or electric force, or even of a line of gravitating force, except as it and they are manifest in and by substances; I believe that, in the experiments I describe in the paper, light has been magnetically affected, *i. e.* that that which is magnetic in the forces of matter has been affected, and in turn has affected that which is truly magnetic in the force of light: by the term magnetic I include here either of the peculiar exertions of the power of a magnet, whether it be that which is manifest in the magnetic or the diamagnetic class of bodies. The phrase "illumination of the lines of magnetic force" has been understood to imply that I had rendered them luminous. This was not within my thought. I intended to express that the line of magnetic force was illuminated as the earth is illuminated by the sun, or the spider's web illuminated by the astronomer's lamp. Employing a ray of light, we can tell, *by the eye*, the direction of the magnetic lines through a body; and by the alteration of the ray and its optical effect on the eye, can see the course of the lines just as we can see the course of a thread of glass, or any other transparent substance, rendered visible by the light: and this was what I meant by *illumination*, as the paper fully explains.—December 15, 1845. M. F.

words, are so directly related and mutually dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action*. In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.

2147. This strong persuasion extended to the powers of light, and led, on a former occasion, to many exertions, having for their object the discovery of the direct relation of light and electricity, and their mutual action in bodies subject jointly to their power†; but the results were negative and were afterwards confirmed, in that respect, by WARTMANN‡.

2148. These ineffectual exertions, and many others which were never published, could not remove my strong persuasion derived from philosophical considerations; and, therefore, I recently resumed the inquiry by experiment in a most strict and searching manner, and have at last succeeded in *magnetizing and electrifying a ray of light, and in illuminating a magnetic line of force.* These results, without entering into the detail of many unproductive experiments, I will describe as briefly and clearly as I can.

2149. But before I proceed to them, I will define the meaning I connect with certain terms which I shall have occasion to use:—thus, by *line of magnetic force*, or *magnetic line of force*, or *magnetic curve*, I mean that exercise of magnetic force which is exerted in the lines usually called magnetic curves, and which equally exist as passing from or to magnetic poles, or forming concentric circles round an electric current. By *line of electric force*, I mean the force exerted in the lines joining two bodies, acting on each other according to the principles of static electric induction (1161, &c.), which may also be either in curved or straight lines. By a *diamagnetic*, I mean a body through which lines of magnetic force are passing, and which does not by their action assume the usual magnetic state of iron or loadstone.

2150. A ray of light issuing from an Argand lamp, was polarized in a horizontal plane by reflection from a surface of glass, and the polarized ray passed through a NICHOL'S eye-piece revolving on a horizontal axis, so as to be easily examined by the latter. Between the polarizing mirror and the eye-piece, two powerful electro-magnetic poles were arranged, being either the poles of a horse-shoe magnet, or the contrary poles of two cylinder magnets; they were separated from each other about two inches in the direction of the line of the ray, and so placed, that, if on the same side of the polarized ray, it might pass near them; or, if on contrary sides, it might go between them, its direction being always parallel, or nearly so, to the magnetic lines of force (2149.). After that, any transparent substance placed between the two poles, would have passing through it, both the polarized ray and the magnetic lines of force at the same time and in the same direction.

* Experimental Researches, 57, 366, 376, 877, 961, 2071.

† Philosophical Transactions, 1834. Experimental Researches, 951–955.

‡ Archives de l'Electricité, ii. pp. 596–600.

2151. Sixteen years ago I published certain experiments made upon optical glass*, and described the formation and general characters of one variety of heavy glass, which, from its materials, was called silicated borate of lead. It was this glass which first gave me the discovery of the relation between light and magnetism, and it has power to illustrate it in a degree beyond that of any other body; for the sake of perspicuity I will first describe the phenomena as presented by this substance.

2152. A piece of this glass, about two inches square and 0·5 of an inch thick, having flat and polished edges, was placed as a *diamagnetic* (2149.) between the poles (not as yet magnetized by the electric current), so that the polarized ray should pass through its length; the glass acted as air, water, or any other indifferent substance would do; and if the eye-piece were previously turned into such a position that the polarized ray was extinguished, or rather the image produced by it rendered invisible, then the introduction of this glass made no alteration in that respect. In this state of circumstances the force of the electro-magnet was developed, by sending an electric current through its coils, and immediately the image of the lamp-flame became visible, and continued so as long as the arrangement continued magnetic. On stopping the electric current, and so causing the magnetic force to cease, the light instantly disappeared; these phenomena could be renewed at pleasure, at any instant of time, and upon any occasion, showing a perfect dependence of cause and effect.

2153. The voltaic current which I used upon this occasion, was that of five pair of Grove's construction, and the electro-magnets were of such power that the poles would singly sustain a weight of from twenty-eight to fifty-six, or more, pounds. A person looking for the phenomenon for the first time would not be able to see it with a weak magnet.

2154. The character of the force thus impressed upon the diamagnetic is that of *rotation*; for when the image of the lamp-flame has thus been rendered visible, revolution of the eye-piece to the right or left, more or less, will cause its extinction; and the further motion of the eye-piece to the one side or other of this position will produce the reappearance of the light, and that with complementary tints, according as this further motion is to the right- or left-hand.

2155. When the pole nearest to the observer was a marked pole, *i. e.* the same as the north end of a magnetic needle, and the further pole was unmarked, the rotation of the ray was right-handed; for the eye-piece had to be turned to the right-hand, or clock fashion, to overtake the ray and restore the image to its first condition. When the poles were reversed, which was instantly done by changing the direction of the electric current, the rotation was changed also and became left-handed, the altera-

* Philosophical Transactions, 1830, p. 1. I cannot resist the occasion which is thus offered to me of mentioning the name of Mr. Anderson, who came to me as an assistant in the glass experiments, and has remained ever since in the Laboratory of the Royal Institution. He has assisted me in all the researches into which I have entered since that time, and to his care, steadiness, exactitude, and faithfulness in the performance of all that has been committed to his charge, I am much indebted.—M. F.

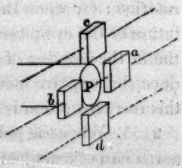
tion being to an equal degree in extent as before. The direction was always the same for the same *line of magnetic force* (2149.).

2156. When the diamagnetic was placed in the numerous other positions, which can easily be conceived, about the magnetic poles, results were obtained more or less marked in extent, and very definite in character, but of which the phenomena just described may be considered as the chief example: they will be referred to, as far as is necessary, hereafter.

2157. The same phenomena were produced in the silicated borate of lead (2151.) by the action of a good ordinary steel horse-shoe magnet, no electric current being now used. The results were feeble, but still sufficient to show the perfect identity of action between electro-magnets and common magnets in this their power over light.

2158. Two magnetic poles were employed end-ways, *i. e.* the cores of the electro-magnets were hollow iron cylinders, and the ray of polarized light passed along their axes and through the diamagnetic placed between them: the effect was the same.

2159. One magnetic pole only was used, that being one end of a powerful cylinder electro-magnet. When the heavy glass was beyond the magnet, being close to it but between the magnet and the polarizing reflector, the rotation was in one direction, dependent on the nature of the pole; when the diamagnetic was on the near side, being close to it but between it and the eye, the rotation for the same pole was in the contrary direction to what it was before; and when the magnetic pole was changed, both these directions were changed with it. When the heavy glass was placed in a corresponding position to the pole, but above or below it, so that the *magnetic curves* were no longer passing through the glass parallel to the ray of polarized light, but rather perpendicular to it, then no effect was produced. These particularities may be understood by reference to fig. 1, where *a* and *b* represent the first positions of the diamagnetic, and *c* and *d* the latter positions, the course of the ray being marked by the dotted line. If also the glass were placed directly at the end of the magnet, then no effect was produced on a ray passing in the direction here described, though it is evident, from what has been already said (2155.), that a ray passing *parallel* to the magnetic lines through the glass so placed, would have been affected by it.



2160. Magnetic lines, then, in passing through silicated borate of lead, and a great number of other substances (2173.), cause these bodies to act upon a polarized ray of light when the lines are parallel to the ray, or in proportion as they are parallel to it: if they are perpendicular to the ray, they have no action upon it. They give the diamagnetic the power of rotating the ray; and the *law* of this action on light is, that if a magnetic line of force be *going from* a north pole, or *coming* from a south pole, along the path of a polarized ray coming to the observer, it will rotate that ray to the right-hand; or, that if such a line of force be coming from a north pole, or going rom a south pole, it will rotate such a ray to the left-hand.

2161. If a cork or a cylinder of glass, representing the diamagnetic, be marked at its ends with the letters N and S, to represent the poles of a magnet, the line joining these letters may be considered as a magnetic line of force; and further, if a line be traced round the cylinder with arrow heads on it to represent direction, as in the figure, such a simple model, held up before the eye, will express the whole of the law, and give every position and consequence of direction resulting from it. If a watch be considered as the diamagnetic, the north pole of a magnet being imagined against the face, and a south pole against the back, then the motion of the hands will indicate the direction of rotation which a ray of light undergoes by magnetization.

2162. I will now proceed to the different circumstances which affect, limit, and define the extent and nature of this new power of action on light.

2163. In the first place, the rotation appears to be in proportion to the extent of the diamagnetic through which the ray and the magnetic lines pass. I preserved the strength of the magnet and the interval between its poles constant, and then interposed different pieces of the same heavy glass (2151.) between the poles. The greater the extent of the diamagnetic in the line of the ray, whether in one, two, or three pieces, the greater was the rotation of the ray; and, as far as I could judge by these first experiments, the amount of rotation was exactly proportionate to the extent of diamagnetic through which the ray passed. No addition or diminution of the heavy glass on the *side* of the course of the ray made any difference in the effect of that part through which the ray passed.

2164. The power of rotating the ray of light *increased* with the intensity of the magnetic lines of force. This general effect is very easily ascertained by the use of electro-magnets; and within such range of power as I have employed, it appears to be directly proportionate to the intensity of the magnetic force.

2165. Other bodies, besides the heavy glass, possess the same power of becoming, under the influence of magnetic force, active on light (2173.). When these bodies possess a rotative power of their own, as is the case with oil of turpentine, sugar, tartaric acid, tartrates, &c., the effect of the magnetic force is to add to, or subtract from, their specific force, according as the natural rotation and that induced by the magnetism is right or left-handed (2231.).

2166. I could not perceive that this power was affected by any degree of motion which I was able to communicate to the diamagnetic, whilst jointly subject to the action of the magnetism and the light.

2167. The interposition of copper, lead, tin, silver, and other ordinary non-magnetic bodies in the course of the magnetic curves, either between the pole and the diamagnetic, or in other positions, produced no effect either in kind or degree upon the phenomena.

2168. Iron frequently affected the results in a very considerable degree; but it always appeared to be, either by altering the direction of the magnetic lines, or dis-

posing within itself of their force. Thus, when the two contrary poles were on one side of the polarized ray (2150.), and the heavy glass in its best position between them and in the ray (2152.), the bringing of a large piece of iron near to the glass on the other side of the ray, caused the power of the diamagnetic to fall. This was because certain lines of magnetic force, which at first passed through the glass parallel to the ray, now crossed the glass and the ray; the iron giving two contrary poles opposite the poles of the magnet, and thus determining a new course for a certain portion of the magnetic power, and that across the polarized ray.

2169. Or, if the iron, instead of being applied on the opposite side of the glass, were applied on the same side with the magnet, either near it or in contact with it, then, again, the power of the diamagnetic fell, simply because the power of the magnet was diverted from it into a new direction. These effects depend much of course on the intensity and power of the magnet, and on the size and softness of the iron.

2170. The electro-helices (2190.) without the iron cores were very feeble in power, and indeed hardly sensible in their effect. With the iron cores they were powerful, though no more electricity was then passing through the coils than before (1071.). This shows, in a very simple manner, that the phenomena exhibited by light under these circumstances, is directly connected with the magnetic form of force supplied by the arrangement. Another effect which occurred illustrated the same point. When the contact at the voltaic battery is made, and the current sent round the electro-magnet, the image produced by the rotation of the polarized ray does not rise up to its full lustre immediately, but increases for a couple of seconds, gradually acquiring its greatest intensity; on breaking the contact, it sinks instantly and disappears apparently at once. The gradual rise in brightness is due to the *time* which the iron core of the magnet requires to evolve all that magnetic power which the electric current can develope in it; and as the magnetism rises in intensity, so does its effect on the light increase in power; hence the progressive condition of the rotation.

2171. I cannot as yet find that the heavy glass (2151.), when in this state, *i. e.* with magnetic lines of force passing through it, exhibits any increased degree, or has any specific magneto-inductive action of the recognized kind. I have placed it in large quantities, and in different positions, between magnets and magnetic needles, having at the time very delicate means of appreciating any difference between it and air, but could find none.

2172. Using water, alcohol, mercury, and other fluids contained in very large delicate thermometer-shaped vessels, I could not discover that any difference in volume occurred when the magnetic curves passed through them.

2173. It is time that I should pass to a consideration of this power of magnetism over light as exercised, not only in the silicated borate of lead (2151.), but in many

other substances; and here we perceive, in the first place, that if all transparent bodies possess the power of exhibiting the action, they have it in very different degrees, and that up to this time there are some that have not shown it at all.

2174. Next, we may observe, that bodies that are exceedingly different to each other in chemical, physical, and mechanical properties, develope this effect; for solids and liquids, acids, alkalies, oils, water, alcohol, ether, all possess the power.

2175. And lastly, we may observe, that in all of them, though the degree of action may differ, still it is always the same in kind, being a rotative power over the ray of light; and further, the direction of the rotation is, in every case, independent of the nature or state of the substance, and dependent upon the direction of the magnetic line of force, according to the law before laid down (2160.).

2176. Amongst the substances in which this power of action is found, I have already distinguished the *silico-borate of lead* (2151.) as eminently fitted for the purpose of exhibiting the phenomena. I regret that it should be the best, since it is not likely to be in the possession of many, and few will be induced to take the trouble of preparing it. If made, it should be well annealed, for otherwise the pieces will have considerable power of depolarizing light, and then the particular phenomena under consideration are much less strikingly observed. The *borate of lead*, however, is a substance much more fusible, softening at the heat of boiling oil, and therefore far more easily prepared in the form of glass plates and annealed; and it possesses as much magneto-rotative power over light as the silico-borate itself. *Flint-glass* exhibits the property, but in a less degree than the substances above. Crown-glass shows it, but in a still smaller degree.

2177. Whilst employing crystalline bodies as diamagnetics, I generally gave them that position in which they did not affect the polarized ray, and then induced the magnetic curves through them. As a class, they seemed to resist the assumption of the rotating state. *Rock-salt* and *fluor-spar* gave evidence of the power in a slight degree; and I think that a crystal of alum did the same, but its ray length in the transparent part was so small that I could not ascertain the fact decisively. Two specimens of transparent fluor, lent me by Mr. Tennant, gave the effect.

2178. Rock-crystal, four inches across, gave no indications of action on the ray, neither did smaller crystals, nor cubes about three-fourths of an inch in the side, which were so cut as to have two of their faces perpendicular to the axis of the crystal (1692, 1693.), though they were examined in every direction.

2179. *Iceland spar* exhibited no signs of effect, either in the form of rhomboids, or of cubes like those just described (1695.).

2180. *Sulphate of baryta*, *sulphate of lime*, and *carbonate of soda*, were also without action on the light.

2181. A piece of fine clear *ice* gave me no effect. I cannot however say there is none, for the effect of water in the same mass would be very small, and the irregularity of the flattened surface from the fusion of the ice and flow of water, made the observation very difficult.

2182. With some degree of curiosity and hope, I put gold-leaf into the magnetic lines, but could perceive no effect. Considering the extremely small dimensions of the length of the path of the polarized ray in it, any positive result was hardly to be expected.

2183. In experiments with liquids, a very good method of observing the effect, is to inclose them in bottles from $1\frac{1}{2}$ to 3 or 4 inches in diameter, placing these in succession between the magnetic poles (2150.), and bringing the analysing eye-piece so near to the bottle, that, by adjustment of the latter, its cylindrical form may cause a diffuse but useful image of the lamp-flame to be seen through it: the light of this image is easily distinguished from that which passes by irregular refraction through the striæ and deformations of the glass, and the phenomena being looked for in this light are easily seen.

2184. Water, alcohol, and ether, all show the effect; water most, alcohol less, and ether the least. All the fixed oils which I have tried, including almond, castor, olive, poppy, linseed, sperm, elaine from hog's lard, and distilled resin oil, produce it. The essential oils of turpentine, bitter almonds, spike lavender, lavender, jessamine, cloves, and laurel, produce it. Also naphtha of various kinds, melted spermaceti, fused sulphur, chloride of sulphur, chloride of arsenic, and every other liquid substance which I had at hand and could submit in sufficient bulk to experiment.

2185. Of aqueous solutions I tried 150 or more, including the soluble acids, alkalies and salts, with sugar, gum, &c., the list of which would be too long to give here, since the great conclusion was, that the exceeding diversity of substance caused no exception to the general result, for all the bodies showed the property. It is indeed more than probable, that in all these cases the water and not the other substance present was the ruling matter. The same general result was obtained with alcoholic solutions.

2186. Proceeding from liquids to air and gaseous bodies, I have here to state that, as yet, I have not been able to detect the exercise of this power in any one of the substances in this class. I have tried the experiment with bottles 4 inches in diameter, and the following gases: oxygen, nitrogen, hydrogen, nitrous oxide, olefiant gas, sulphurous acid, muriatic acid, carbonic acid, carbonic oxide, ammonia, sulphuretted hydrogen, and bromine vapour, at ordinary temperatures; but they all gave negative results. With air, the trial has been carried, by another form of apparatus, to a much higher degree, but still ineffectually (2212.).

2187. Before dismissing the consideration of the substances which exhibited this power, and in reference to those in which it was superinduced upon bodies possessing, naturally, rotative force (2165. 2231.), I may record, that the following are the substances submitted to experiment: castor oil, resin oil, oil of spike lavender, of laurel, Canada balsam, alcoholic solution of camphor, alcoholic solution of camphor and corrosive sublimate, aqueous solutions of sugar, tartaric acid, tartrate of soda, tartrate of potassa and antimony, tartaric and boracic acid, and sulphate of nickel, which rotated to the right-hand; copaiba balsam, which rotated the ray to the left-hand; and two

specimens of camphine or oil of turpentine, in one of which the rotation was to the right-hand, and in the other to the left. In all these cases, as already said (2165.), the superinduced magnetic rotation was according to the general law (2160.), and without reference to the previous power of the body.

2188. Camphor being melted in a tube about an inch in diameter, exhibited high natural rotative force, but I could not discover that the magnetic curves induced additional force in it. It may be, however, that the shortness of the ray length and the quantity of coloured light left, even when the eye-piece was adjusted to the most favourable position for darkening the image produced by the naturally rotated ray, rendered the small magneto-power of the camphor insensible.

¶ ii. *Action of electric currents on light.*

2189. From a consideration of the nature and position of the lines of magnetic and electric force, and the relation of a magnet to a current of electricity, it appeared almost certain that an electric current would give the same result of action on light as a magnet; and, in the helix, would supply a form of apparatus in which great lengths of diamagnetics, and especially of such bodies as appeared to be but little affected between the poles of the magnet, might be submitted to examination and their effect exalted: this expectation was, by experiment, realized.

2190. Helices of copper wire were employed, three of which I will refer to. The first, or *long helix*, was 0·4 of an inch internal diameter; the wire was 0·03 of an inch in diameter, and having gone round the axis from one end of the helix to the other, then returned in the same manner, forming a coil sixty-five inches long, double in its whole extent, and containing 1240 feet of wire.

2191. The second, or *medium helix*, is nineteen inches long, 1·87 inch internal diameter, and three inches external diameter. The wire is 0·2 of an inch in diameter, and eighty feet in length, being disposed in the coil as two concentric spirals. The electric current, in passing through it, is not divided, but traverses the whole length of the wire.

2192. The third, or *Woolwich helix*, was made under my instruction for the use of Lieut.-Colonel Sabine's establishment at Woolwich. It is 26·5 inches long, 2·5 inches internal diameter, and 4·75 inches external diameter. The wire is 0·17 of an inch in diameter, and 501 feet in length. It is disposed in the coil in four concentric spirals connected end to end, so that the whole of the electric current employed passes through all the wire.

2193. The long helix (2190.) acted very feebly on a magnetic needle placed at a little distance from it; the medium helix (2191.) acted more powerfully, and the Woolwich helix (2192.) very strongly; the same battery of ten pairs of Grove's plate being employed in all cases.

2194. Solid bodies were easily subjected to the action of these electro-helices, being for that purpose merely cut into the form of bars or prisms with flat and polished

ends, and then introduced as cores into the helices. For the purpose of submitting liquid bodies to the same action, tubes of glass were provided, furnished at the ends with caps; the cylindrical part of the cap was brass, and had a tubular aperture for the introduction of the liquids, but the end was a flat glass plate. When the tube was intended to contain aqueous fluids, the plates were attached to the caps, and the caps to the tube by Canada balsam; when the tube had to contain alcohol, ether or essential oils, a thick mixture of powdered gum with a little water was employed as the cement.

2195. The general effect produced by this form of apparatus may be stated as follows:—The tube within the long helix (2190.) was filled with distilled water and placed in the line of the polarized ray, so that by examination through the eye-piece (2150.), the image of the lamp-flame produced by the ray could be seen through it. Then the eye-piece was turned until the image of the flame disappeared, and, afterwards, the current of ten pairs of plates sent through the helix; instantly the image of the flame reappeared, and continued as long as the electric current was passing through the helix; on stopping the current the image disappeared. The light did not rise up gradually, as in the case of electro-magnets (2170.), but instantly. These results could be produced at pleasure. In this experiment we may, I think, justly say that a ray of light is electrified and the electric forces illuminated.

2196. The phenomena may be made more striking, by the adjustment of a lens of long focus between the tube and the polarizing mirror, or one of short focus between the tube and the eye; and where the helix, or the battery, or the substance experimented with, is feeble in power, such means offer assistance in working out the effects: but, after a little experience, they are easily dispensed with, and are only useful as accessories in doubtful cases.

2197. In cases where the effect is feeble, it is more easily perceived if the Nichol eye-piece be adjusted, not to the perfect extinction of the ray, but a little short of or beyond that position; so that the image of the flame may be but just visible. Then, on the exertion of the power of the electric current, the light is either increased in intensity, or else diminished, or extinguished, or even re-illuminated on the other side of the dark condition; and this change is more easily perceived than if the eye began to observe from a state of utter darkness. Such a mode of observing also assists in demonstrating the rotatory character of the action on light; for, if the light be made visible beforehand by the motion of the eye-piece in one direction, and the power of the current be to *increase* that light, an instant only suffices, after stopping the current, to move the eye-piece in the other direction until the light is apparent as at first, and then the power of the current will be to *diminish* it; the tints of the lights being affected also at the same time.

2198. When the current was sent round the helix in one direction, the rotation induced upon the ray of light was one way; and when the current was changed to the contrary direction, the rotation was the other way. In order to express the direc-

tion, I will assume, as is usually done, that the current passes from the zinc through the acid to the platinum in the same cell (663. 667. 1627.): if such a current pass under the ray towards the right, upwards on its right side, and over the ray towards the left, it will give left-handed rotation to it; or, if the current pass over the ray to the right, down on the right side, and under it towards the left, it will induce it to rotate to the right-hand.

2199. The LAW, therefore, by which an electric current acts on a ray of light is easily expressed. When an electric current passes round a ray of polarized light in a plane perpendicular to the ray, it causes the ray to revolve on its axis, as long as it is under the influence of the current, in the *same direction* as that in which the current is passing.

2200. The simplicity of this law, and its identity with that given before, as expressing the action of magnetism on light (2160.), is very beautiful. A model is not wanted to assist the memory; but if that already described (2161.) be looked at, the line round it will express at the same time the direction both of the current and the rotation. It will indeed do much more; for if the cylinder be considered as a piece of iron, and not a piece of glass or other diamagnetic, placed between the two poles N and S, then the line round it will represent the direction of the currents, which, according to AMPÈRE's theory, are moving round its particles; or if it be considered as a core of iron (in place of a core of water), having an electric current running round it in the direction of the line, it will also represent such a magnet as would be formed if it were placed between the poles whose marks are affixed to its ends.

2201. I will now notice certain points respecting the degree of this action under different circumstances. By using a tube of water (2194.) as long as the helix, but placing it so that more or less of the tube projected at either end of the helix, I was able, in some degree, to ascertain the effect of length of the diamagnetic, the force of the helix and current remaining the same. The greater the column of water subjected to the action of the helix, the greater was the rotation of the polarized ray; and the amount of rotation seemed to be directly proportionate to the length of fluid round which the electric current passed.

2202. A short tube of water, or a piece of heavy glass, being placed in the axis of the Woolwich helix (2192.), seemed to produce equal effect on the ray of light, whether it were in the middle of the helix or at either end; provided it was always within the helix and in the line of the axis. From this it would appear that every part of the helix has the same effect; and, that by using long helices, substances may be submitted to this kind of examination which could not be placed in sufficient length between the poles of magnets (2150.).

2203. A tube of water as long as the Woolwich helix (2192.), but only 0·4 of an inch in diameter, was placed in the helix parallel to the axis, but sometimes in the axis and sometimes near the side. No apparent difference was produced in these different situations; and I am inclined to believe (without being quite sure) that the

action on the ray is the same, wherever the tube is placed, within the helix, in relation to the axis. The same result was obtained when a larger tube of water was looked through, whether the ray passed through the axis of the helix and tube, or near the side.

2204. If bodies be introduced into the helix possessing, naturally, rotating force, then the rotating power given by the electric current is superinduced upon them, exactly as in the cases already described of magnetic action (2165. 2187.).

2205. A helix, twenty inches long and 0·3 of an inch in diameter, was made of uncovered copper wire, 0·05 of an inch in diameter, in close spirals. This was placed in a large tube of water, so that the fluid, both in the inside and at the outside of the helix, could be examined by the polarized ray. When the current was sent *through* the helix, the water within it received rotating power; but no trace of such an action on the light was seen on the outside of the helix, even in the line most close to the uncovered wire.

2206. The water was inclosed in brass and copper tubes, but this alteration caused not the slightest change in the effect.

2207. The water in the brass tube was put into an *iron* tube, much longer than either the Woolwich helix or the brass tube, and quite one eighth of an inch thick in the side; yet when placed in the Woolwich helix (2192.), the water rotated the ray of light apparently as well as before.

2208. An iron bar, one inch square and longer than the helix, was put into the helix, and the small water tube (2203.) upon it. The water exerted as much action on the light as before.

2209. Three iron tubes, each twenty-seven inches long and one-eighth of an inch in thickness in the side, were selected of such diameters as to pass easily one into the other, and the whole into the Woolwich helix (2192.). The smaller one was supplied with glass ends and filled with water; and being placed in the axis of the Woolwich helix, had a certain amount of rotating power over the polarized ray. The second tube was then placed over this, so that there was now a thickness of iron equal to two-eighths of an inch between the water and the helix; the water had *more* power of rotation than before. On placing the third tube of iron over the two former, the power of the water *fell*, but was still very considerable. These results are complicated, being dependent on the new condition which the character of iron gives to its action on the forces. Up to a certain amount, by increasing the development of magnetic forces, the helix and core, *as a whole*, produce increased action on the water; but on the addition of more iron and the disposal of the forces through it, their action is removed in part from the water and the rotation is lessened.

2210. Pieces of heavy glass (2151.), placed in iron tubes in the helices, produced similar effects.

2211. The bodies which were submitted to the action of an electric current in a helix, in the manner already described, were as follows:—Heavy glass (2151. 2176.),

water, solution of sulphate of soda, solution of tartaric acid, alcohol, ether, and oil of turpentine; all of which were affected, and acted on light exactly in the manner described in relation to magnetic action (2173.).

2212. I submitted *air* to the influence of these helices carefully and anxiously, but could not discover any trace of action on the polarized ray of light. I put the long helix (2190.) into the other two (2191. 2192.), and combined them all into one consistent series, so as to accumulate power, but could not observe any effect of them on light passing through air.

2213. In the use of helices, it is necessary to be aware of one effect, which might otherwise cause confusion and trouble. At first, the wire of the long helix (2190.) was wound directly upon the thin glass tube which served to contain the fluid. When the electric current passed through the helix it raised the temperature of the metal, and that gradually raised the temperature of the glass and the film of water in contact with it, and so the cylinder of water, warmer at its surface than its axis, acted as a lens, gathering and sending rays of light to the eye, and continuing to act for a time after the current was stopped. By separating the tube of water from the helix, and by other precautions, this source of confusion is easily avoided.

2214. Another point of which the experimenter should be aware, is the difficulty, and almost impossibility, of obtaining a piece of glass which, especially after it is cut, does not depolarize light. When it does depolarize, difference of position makes an immense difference in the appearance. By always referring to the parts that do not depolarize, as the black cross, for instance, and by bringing the eye as near as may be to the glass, this difficulty is more or less overcome.

2215. For the sake of supplying a general indication of the amount of this induced rotating force in two or three bodies, and without any pretence of offering correct numbers, I will give, generally, the result of a few attempts to measure the force, and compare it with the natural power of a specimen of oil of turpentine. A very powerful electro-magnet was employed, with a *constant* distance between its poles of $2\frac{1}{2}$ inches. In this space was placed different substances; the amount of rotation of the eye-piece observed several times and the average taken, as expressing the rotation for the ray length of substance used. But as the substances were of different dimensions, the ray lengths were, by calculation, corrected to one standard length, upon the assumption that the power was proportionate to this length (2163.). The oil of turpentine was of course observed in its natural state, i. e. without magnetic action. Making water 1, the numbers were as follows:—

Oil of turpentine	11·8
Heavy glass (2151.) . . .	6·0
Flint-glass	2·8
Rock salt	2·2

Water	1·0
Alcohol	less than water.
Ether	less than alcohol.

2216. In relation to the action of magnetic and electric forces on light, I consider, that to know the conditions under which there is no apparent action, is to add to our knowledge of their mutual relations; and will, therefore, very briefly state how I have lately combined these forces, obtaining no apparent result (955.).

2217. Heavy glass, flint-glass, rock crystal, Iceland spar, oil of turpentine, and air, had a polarized ray passed through them; and, at the same time, lines of electrostatic tension (2149.) were, by means of coatings, the Leyden jar, and the electric machine, directed across the bodies, parallel to the polarized ray, and perpendicular to it, both in and across the plane of polarization; but without any visible effect. The tension of a rapidly recurring, induced secondary current, was also directed upon the same bodies and upon water (as an electrolyte), but with the same negative result.

2218. A polarized ray, powerful magnetic lines of force, and the electric lines of force (2149.) just described, were combined in various directions in their action on heavy glass (2151. 2176.), but with no other result than that due to the mutual action of the magnetic lines of light, already described in this paper.

2219. A polarized ray and electric currents were combined in every possible way in electrolytes (951–954). The substances used were distilled water, solution of sugar, dilute sulphuric acid, solution of sulphate of soda, using platinum electrodes; and solution of sulphate of copper, using copper electrodes: the current was sent along the ray, and perpendicular to it in two directions at right angles with each other; the ray was made to rotate, by altering the position of the polarizing mirror, that the plane of polarization might be varied; the current was used as a continuous current, as a rapidly intermitting current, and as a rapidly alternating double current of induction; but in no case was any trace of action perceived.

2220. Lastly, a ray of polarized light, electric currents, and magnetic lines of force, were directed in every possible way through dilute sulphuric acid and solution of sulphate of soda, but still with negative results, except in those positions where the phenomena already described were produced. In one arrangement, the current passed in the direction of radii from a central to a circumferential electrode, the contrary magnetic poles being placed above and below; and the arrangements were so good, that when the electric current was passing, the fluid rapidly rotated; but a polarized ray sent horizontally across this arrangement was not at all affected. Also, when the ray was sent vertically through it, and the eye-piece moved to correspond to the rotation impressed upon the ray in this position by the magnetic curves alone, the superinduction of the passage of the electric current made not the least difference in the effect upon the ray.

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¶ iii. *General considerations.*

2221. Thus is established, I think for the first time*, a true, direct relation and dependence between light and the magnetic and electric forces; and thus a great addition made to the facts and considerations which tend to prove that all natural forces are tied together, and have one common origin (2146.). It is, no doubt, difficult in the present state of our knowledge to express our expectation in exact terms; and, though I have said that another of the powers of nature is, in these experiments, directly related to the rest, I ought, perhaps, rather to say that another form of the great power is distinctly and directly related to the other forms; or, that the great power manifested by particular phenomena in particular forms, is here further identified and recognised, by the direct relation of its form of light to its forms of electricity and magnetism.

2222. The relation existing between *polarized* light and magnetism and electricity, is even more interesting than if it had been shown to exist with common light only. It cannot but extend to common light; and, as it belongs to light made, in a certain respect, more precise in its character and properties by polarization, it collates and connects it with these powers, in that duality of character which they possess, and yields an opening, which before was wanting to us, for the appliance of these powers to the investigation of the nature of this and other radiant agencies.

2223. Referring to the conventional distinction before made (2149.), it may be again stated, that it is the magnetic lines of force *only* which are effectual on the rays of light, and they *only* (in appearance) when parallel to the ray of light, or as they tend to parallelism with it. As, in reference to matter not magnetic after the manner of iron, the phenomena of electric induction and electrolyzation show a vast superiority in the energy with which electric forces can act as compared to magnetic forces, so here, in another direction and in the peculiar and correspondent effects which belong to magnetic forces, they are shown, in turn, to possess great superiority, and to have their full equivalent of action on the same kind of matter.

2224. The magnetic forces do not act on the ray of light directly and without the intervention of matter, but through the mediation of the substance in which they and the ray have a simultaneous existence; the substances and the forces giving to and receiving from each other the power of acting on the light. This is shown by the

* I say, for the first time, because I do not think that the experiments of Morrichini on the production of magnetism by the rays at the violet end of the spectrum prove any such relation. When in Rome with Sir H. Davy in the month of May 1814, I spent several hours at the house of Morrichini, working with his apparatus and under his directions, but could not succeed in magnetising a needle. I have no confidence in the effect as a *direct* result of the action of the sun's rays; but think, that when it has occurred it has been secondary, incidental, and perhaps even accidental; a result that might well happen with a needle that was preserved during the whole experiment in a north and south position.

January 2, 1846.—I should not have written "for the first time" as above, if I had remembered Mr. Christie's experiments and papers on the Influence of the Solar Rays on Magnets, communicated in the Philosophical Transactions for 1826, p. 219, and 1828, p. 379.—M. F.

non-action of a vacuum, of air or gases; and it is also further shown by the special degree in which different matters possess the property. That magnetic force acts upon the ray of light always with the same character of manner and in the same direction, independent of the different varieties of substance, or their states of solid or liquid, or their specific rotative force (2232.), shows that the magnetic force and the light have a direct relation: but that substances are necessary, and that these act in different degrees, shows that the magnetism and the light act on each other through the intervention of the matter.

2225. Recognizing or perceiving *matter* only by its powers, and knowing nothing of any imaginary nucleus, abstract from the idea of these powers, the phenomena described in this paper much strengthen my inclination to trust in the views I have on a former occasion advanced in reference to its nature*.

2226. It cannot be doubted that the magnetic forces act upon and affect the internal constitution of the diamagnetic, just as freely in the dark as when a ray of light is passing through it; though the phenomena produced by light seem, as yet, to present the only means of observing this constitution and the change. Further, any such change as this must belong to opake bodies, such as wood, stone, and metal; for as diamagnetics, there is no distinction between them and those which are transparent. The degree of transparency can at the utmost, in this respect, only make a distinction between the individuals of a class.

2227. If the magnetic forces had made these bodies magnets, we could, by light, have examined a transparent magnet; and that would have been a great help to our investigation of the forces of matter. But it does not make them magnets (2171.), and therefore the molecular condition of these bodies, when in the state described, must be specifically distinct from that of magnetized iron, or other such matter, and must be *a new magnetic condition*; and as the condition is a state of tension (manifested by its instantaneous return to the normal state when the magnetic induction is removed), so the *force* which the matter in this state possesses and its mode of action, must be to us a *new magnetic force* or *mode of action* of matter.

2228. For it is impossible, I think, to observe and see the action of magnetic forces, rising in intensity, upon a piece of heavy glass or a tube of water, without also perceiving that the latter acquire properties which are not only *new* to the substance, but are also in subjection to very definite and precise laws (2160. 2199.), and are equivalent in proportion to the magnetic forces producing them.

2229. Perhaps this state is a state of *electric tension tending to a current*; as in magnets, according to AMPÈRE's theory, the state is a state of *current*. When a core of iron is put into a helix, every thing leads us to believe that currents of electricity are produced within it, which rotate or move in a plane perpendicular to the axis of the helix. If a diamagnetic be placed in the same position, it acquires power to make light rotate in the same plane. The state it has received is a state of tension, but it

* A speculation, &c. Philosophical Magazine, 1844, vol. xxiv. p. 136.

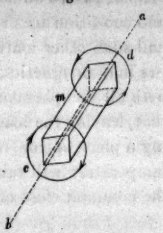
has not passed on into currents, though the acting force and every other circumstance and condition are the same as those which do produce currents in iron, nickel, cobalt, and such other matters as are fitted to receive them. Hence the idea that there exists in diamagnetics, under such circumstances, a tendency to currents, is consistent with all the phenomena as yet described, and is further strengthened by the fact, that, leaving the loadstone or the electric current, which by inductive action is rendering a piece of iron, nickel, or cobalt magnetic, perfectly unchanged, a mere change of temperature will take from these bodies their extra power, and make them pass into the common class of diamagnetics.

2230. The present is, I believe, the first time that the molecular condition of a body, required to produce the circular polarization of light, has been artificially given; and it is therefore very interesting to consider this known state and condition of the body, comparing it with the relatively unknown state of those which possess the power naturally: especially as some of the latter rotate to the right-hand and others to the left; and, as in the cases of quartz and oil of turpentine, the same body chemically speaking, being in the latter instance a liquid with particles free to move, presents different specimens, some rotating one way and some the other.

2231. At first one would be inclined to conclude that the natural state and the state conferred by magnetic and electric forces must be the same, since the effect is the same; but on further consideration it seems very difficult to come to such a conclusion. Oil of turpentine will rotate a ray of light, the power depending upon its particles and not upon the arrangement of the mass. Whichever way a ray of polarized light passes through this fluid, it is rotated in the same manner; and rays passing in every possible direction through it *simultaneously* are all rotated with equal force and according to one common law of direction; *i. e.* either all right-handed or else all to the left. Not so with the rotation superinduced on the *same* oil of turpentine by the magnetic or electric forces: it exists only in one direction, *i. e.* in a plane perpendicular to the magnetic line; and being limited to this plane, it can be changed in direction by a reversal of the direction of the inducing force. The direction of the rotation produced by the natural state is connected invariably with the direction of the ray of light; but the power to produce it appears to be possessed in every direction and at all times by the particles of the fluid: the direction of the rotation produced by the induced condition is connected invariably with the direction of the magnetic line or the electric current, and the condition is possessed by the particles of matter, but strictly limited by the line or the current, changing and disappearing with it.

2232. Let *m*, in fig. 3, represent a glass cell filled with oil of turpentine, possessing naturally the power of producing right-hand rotation, and *a b* a polarized ray of light. If the ray proceed from *a* to *b*, and the eye be placed at *b*, the rotation will

Fig. 3.



be right-handed, or according to the direction expressed by the arrow heads on the circle *c*; if the ray proceed from *b* to *a*, and the eye be placed at *a*, the rotation will still be right-handed *to the observer, i. e.* according to the direction indicated on the circle *d*. Let now an electric current pass round the oil of turpentine in the direction indicated on the circle *c*, or magnetic poles be placed so as to produce the same effect (2155.); the particles will acquire a further rotative force (which no motion amongst themselves will disturb), and a ray coming from *a* to *b* will be seen by an eye placed at *b* to rotate to the right-hand more than before, or in the direction on the circle *c*; but pass a ray from *b* to *a*, and observe with the eye at *a*, and the phenomenon is no longer the same as before; for instead of the new rotation being according to the direction indicated on the circle *d*, it will be in the contrary direction, or to the observer's left-hand (2199.). In fact the induced rotation will be added to the natural rotation as respects a ray passing from *a* to *b*, but it will be subtracted from the natural rotation as regards the ray passing from *b* to *a*. Hence the particles of this fluid which rotate by virtue of their natural force, and those which rotate by virtue of the induced force, cannot be in the same condition.

2233. As respects the power of the oil of turpentine to rotate a ray in whatever direction it is passing through the liquid, it may well be, that though all the particles possess the power of rotating the light, only those whose planes of rotation are more or less perpendicular to the ray affect it; and that it is the resultant or sum of forces in any one direction which is active in producing rotation. But even then a striking difference remains, because the resultant in the same plane is not absolute in direction, but relative to the course of the ray, being in the one case as the circle *c*, and in the other as the circle *d*, fig. 3; whereas the resultant of the magnetic or electric induction is absolute, and not changing with the course of the ray, being always either as expressed by *c* or else as indicated by *d*.

2234. All these differences, however, will doubtless disappear or come into harmony as these investigations are extended; and their very existence opens so many paths, by which we may pursue our inquiries, more and more deeply, into the powers and constitution of matter.

2235. Bodies having rotating power of themselves, do not seem by that to have a greater or a less tendency to assume a further degree of the same force under the influence of magnetic or electric power.

2236. Were it not for these and other differences, we might see an analogy between these bodies, which possess at all times the rotating power, as a specimen of quartz which rotates only in one plane, and those to which the power is given by the induction of other forces, as a prism of heavy glass in a helix, on the one hand; and, on the other, a natural magnet and a helix through which the current is passing.

The natural condition of the magnet and quartz, and the constrained condition of the helix and heavy glass, form the link of the analogy in one direction; whilst the supposition of currents existing in the magnet and helix, and only a tendency or tension to currents existing in the quartz and heavy glass, supplies the link in the transverse direction.

2237. As to those bodies which seem as yet to give no indication of the power over light, and therefore none of the assumption of the new magnetic conditions; these may be divided into two classes, the one including air, gases and vapours, and the other rock crystal, Iceland spar, and certain other crystalline bodies. As regards the latter class, I shall give, in the next series of these researches, proofs drawn from phenomena of an entirely different kind, that they do acquire the new magnetic condition; and these being so disposed of for the moment, I am inclined to believe that even air and gases have the power to assume the peculiar state, and even to affect light, but in a degree so small that as yet it has not been made sensible. Still the gaseous state is such a remarkable condition of matter, that we ought not too hastily to assume that the substances which, in the solid and liquid state, possess properties even general in character, always carry these into their gaseous condition.

2238. Rock-salt, fluor-spar, and, I think, alum, affect the ray of light; the other crystals experimented with did not; these are equiaxed and singly refracting, the others are unequiaxed and doubly refracting. Perhaps these instances, with that of the rotation of quartz, may even now indicate a relation between magnetism, electricity, and the crystallizing forces of matter.

2239. All bodies are affected by helices as by magnets, and according to laws which show that the causes of the action are identical as well as the effects. This result supplies another fine proof in favour of the identity of helices and magnets, according to the views of Ampère.

2240. The theory of static induction which I formerly ventured to set forth (1161, &c.), and which depends upon the action of the contiguous particles of the dielectric intervening between the inductric and the inducteous bodies, led me to expect that the same kind of dependence upon the intervening particles would be found to exist in magnetic action; and I published certain experiments and considerations on this point seven years ago (1709—1736.). I could not then discover any peculiar condition of the intervening substance or diamagnetic; but now that I have been able to make out such a state, which is not only a state of tension (2227.), but dependent entirely upon the magnetic lines which pass through the substance, I am more than ever encouraged to believe that the view then advanced is correct.

2241. Although the magnetic and electric forces *appear* to exert no power on the ordinary or on the depolarized ray of light, we can hardly doubt but that they have some special influence, which probably will soon be made apparent by experiment. Neither can it be supposed otherwise than that the same kind of action should take place on the other forms of radiant agents as heat and chemical force.

2242. This mode of magnetic and electric action, and the phenomena presented by it, will, I hope, greatly assist hereafter in the investigation of the nature of transparent bodies, of light, of magnets, and their action one on another, or on magnetic substances. I am at this time engaged in investigating the new magnetic condition, and shall shortly send a further account of it to the Royal Society. What the possible effect of the force may be in the earth as a whole, or in magnets, or in relation to the sun, and what may be the best means of causing light to evolve electricity and magnetism, are thoughts continually pressing upon the mind; but it will be better to occupy both time and thought, aided by experiment, in the investigation and development of real truth, than to use them in the invention of suppositions which may or may not be founded on, or consistent with fact.

Royal Institution,
Oct. 29, 1845.

II. *Experimental Researches in Electricity.—Twentieth Series.*

By MICHAEL FARADAY, *Esq., D.C.L. F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Cor. Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, &c. &c.*

Received December 6,—Read December 18, 1845.

§ 27. *On new magnetic actions, and on the magnetic condition of all matter*.*

¶ i. *Apparatus required.* ¶ ii. *Action of magnets on heavy glass.* ¶ iii. *Action of magnets on other substances acting magnetically on light.* ¶ iv. *Action of magnets on the metals generally.*

2243. THE contents of the last series of these researches were, I think, sufficient to justify the statement, that a new magnetic condition (*i. e.* one new to our knowledge) had been impressed on matter by subjecting it to the action of magnetic and electric forces (2227.); which new condition was made manifest by the powers of action which the matter had acquired over light. The phenomena now to be described are altogether different in their nature; and they prove, not only a magnetic condition of the substances referred to unknown to us before, but also of many

* My friend Mr. WHEATSTONE has this day called my attention to a paper by M. BECQUEREL, "On the magnetic actions excited in all bodies by the influence of very energetic magnets," read to the Academy of Sciences on the 27th of September 1827, and published in the Annales de Chimie, xxxvi. p. 337. It relates to the action of the magnet on a magnetic needle, on soft iron, on the deutoxide and tritoxide of iron, on the tritoxide alone, and on a needle of wood. The author observed, and quotes COULOMB as having also observed, that a needle of wood, under certain conditions, pointed *across* the magnetic curves; and he also states the striking fact that he had found a needle of wood place itself parallel to the wires of a galvanometer. These effects, however, he refers to a degree of magnetism less than that of the tritoxide of iron, but the same in character, for the bodies take the same position. The polarity of steel and iron is stated to be in the direction of the length of the substance, but that of tritoxide of iron, wood and gum-lac, most frequently in the direction of the width, and always when one magnetic pole is employed. "This difference of effect, which establishes a line of demarcation between these two species of phenomena, is due to this, that the magnetism being very feeble in the tritoxide of iron, wood, &c., we may neglect the reaction of the body on itself, and therefore the direct action of the bar ought to overrule it."

As the paper does not refer the phenomena of wood and gum-lac to an elementary *repulsive* action, nor show that they are common to an immense class of bodies, nor distinguish this class, which I have called diamagnetic, from the magnetic class; and, as it makes all magnetic action of one kind, whereas I show that there are two kinds of such action, as distinct from each other as positive and negative electric action are in their way, so I do not think I need alter a word or the date of that which I have written; but am most glad here to acknowledge M. BECQUEREL's important facts and labours in reference to this subject.—M. F. Dec. 5, 1845.

others, including a vast number of opake and metallic bodies, and perhaps all except the magnetic metals and their compounds: and they also, through that condition, present us with the means of undertaking the correlation of magnetic phenomena, and perhaps the construction of a theory of general magnetic action founded on simple fundamental principles.

2244. The whole matter is so new, and the phenomena so varied and general, that I must, with every desire to be brief, describe much which at last will be found to concentrate under simple principles of action. Still, in the present state of our knowledge, such is the only method by which I can make these principles and their results sufficiently manifest.

¶ i. *Apparatus required.*

2245. The effects to be described require magnetic apparatus of great power, and under perfect command. Both these points are obtained by the use of electro-magnets, which can be raised to a degree of force far beyond that of natural or steel magnets; and further, can be suddenly altogether deprived of power, or made energetic to the highest degree, without the slightest alteration of the arrangement, or of any other circumstance belonging to an experiment.

2246. One of the electro-magnets which I use is that already described under the term Woolwich helix (2192.). The soft iron core belonging to it is twenty-eight inches in length and 2·5 inches in diameter. When thrown into action by ten pair of Grove's plates, either end will sustain one or two half-hundred weights hanging to it. The magnet can be placed either in the vertical or the horizontal position. The iron core is a cylinder with flat ends, but I have had a cone of iron made, two inches in diameter at the base and one inch in height, and this placed at the end of the core, forms a conical termination to it, when required.

2247. Another magnet which I have had made has the horse-shoe form. The bar of iron is forty-six inches in length and 3·75 inches in diameter, and is so bent that the extremities forming the poles are six inches from each other; 522 feet of copper wire 0·17 of an inch in diameter and covered with tape, are wound round the two straight parts of the bar, forming two coils on these parts, each sixteen inches in length, and composed of three layers of wire: the poles are, of course, six inches apart, the ends are planed true, and against these move two short bars of soft iron, 7 inches long and $2\frac{1}{2}$ by 1 inch thick, which can be adjusted by screws, and held at any distance less than six inches from each other. The ends of these bars form the opposite poles of contrary name; the magnetic field between them can be made of greater or smaller extent, and the intensity of the lines of magnetic force be proportionately varied.

2248. For the suspension of substances between and near the poles of these magnets, I occasionally used a glass jar, with a plate and sliding wire at the top. Six or eight lengths of cocoon silk being equally stretched, were made into one thread

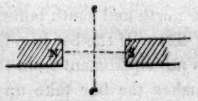
and attached, at the upper end, to the sliding rod, and at the lower end to a stirrup of paper, in which anything to be experimented on could be sustained.

2249. Another very useful mode of suspension was to attach one end of a fine thread, six feet long, to an adjustible arm near the ceiling of the room, and terminating at the lower end by a little ring of copper wire; any substance to be suspended could be held in a simple cradle of fine copper wire having eight or ten inches of the wire prolonged upward; this, being bent into a hook at the superior extremity, gave the means of attachment to the ring. The height of the suspended substance could be varied at pleasure, by bending any part of the wire at the instant into the hook form. A glass cylinder placed between the magnetic poles was quite sufficient to keep the suspended substance free from any motion, due to the agitation of the air.

2250. It is necessary, before entering upon an experimental investigation with such an apparatus, to be aware of the effect of any magnetism which the bodies used may possess; the power of the apparatus to make manifest such magnetism is so great, that it is difficult on that account to find writing-paper fit for the stirrup above mentioned. Before therefore any experiments are instituted, it must be ascertained that the suspending apparatus employed does not point, *i. e.* does not take up a position parallel to the line joining the magnetic poles, by virtue of the magnetic force. When copper suspensions are employed, a peculiar effect is produced (2309.), but when understood, as it will be hereafter, it does not interfere with the results of experiment. The wire should be fine, not magnetic as iron, and the form of the suspending cradle should not be elongated horizontally, but be round or square as to its general dimensions, in that direction.

2251. The substances to be experimented with should be carefully examined, and rejected if not found free from magnetism. Their state is easily ascertained; for, if magnetic, they will either be attracted to the one or the other pole of the great magnet, or else point between them. No examination by smaller magnets, or by a magnetic needle, is sufficient for this purpose.

2252. I shall have such frequent occasion to refer to two chief directions of position across the magnetic field, that to avoid periphrasis, I will here ask leave to use a term or two, conditionally. One of these directions is that from pole to pole, or along the line of magnetic force; I will call it the axial direction: the other is the direction perpendicular to this, and across the line of magnetic force; and for the time, and as respects the space between the poles, I will call it the equatorial direction. Other terms that I may use, I hope will explain themselves.



¶ ii. *Action of magnets on heavy glass.*

2253. The bar of silicated borate of lead, or heavy glass already described as the substance in which magnetic forces were first made effectually to bear on a ray of light (2152.), and which is two inches long, and about 0·5 of an inch wide and thick, was suspended centrally between the magnetic poles (2247.), and left until the effect of torsion was over. The magnet was then thrown into action by making contact at the voltaic battery: immediately the bar moved, turning round its point of suspension, into a position across the magnetic curve or line of force, and after a few vibrations took up its place of rest there. On being displaced by hand from this position, it returned to it, and this occurred many times in succession.

2254. Either end of the bar indifferently went to either side of the axial line. The determining circumstance was simply inclination of the bar one way or the other to the axial line, at the beginning of the experiment. If a particular or marked end of the bar were on one side of the magnetic, or axial line, when the magnet was rendered active that end went further outwards, until the bar had taken up the equatorial position.

2255. Neither did any change in the magnetism of the poles, by change in the direction of the electric current, cause any difference in this respect. The bar went by the shortest course to the equatorial position.

2256. The power which urged the bar into this position was so thoroughly under command, that if the bar were swinging it could easily be hastened in its course into this position, or arrested as it was passing from it, by seasonable contacts at the voltaic battery.

2257. There are two positions of equilibrium for the bar; one stable, the other unstable. When in the direction of the axis or magnetic line of force, the completion of the electric communication causes no change of place; but if it be the least oblique to this position, then the obliquity increases until the bar arrives at the equatorial position; or if the bar be originally in the equatorial position, then the magnetism causes no further changes, but retains it there (2298. 2299. 2384.).

2258. Here then we have a magnetic bar which points east and west, in relation to north and south poles, *i. e.* points perpendicularly to the lines of magnetic force.

2259. If the bar be adjusted so that its point of suspension, being in the axial line, is not equidistant from the poles, but near to one of them, then the magnetism again makes the bar take up a position perpendicular to the magnetic lines of force; either end of the bar being on the one side of the axial line, or the other, at pleasure. But at the same time there is another effect, for at the moment of completing the electric contact, the centre of gravity of the bar recedes from the pole and remains repelled from it as long as the magnet is retained excited. On allowing the magnetism to pass away, the bar returns to the place due to it by its gravity.

2260. Precisely the same effect takes place at the other pole of the magnet. Either of them is able to repel the bar, whatever its position may be, and at the same time the bar is made to assume a position, at right angles, to the line of magnetic force.

2261. If the bar be equidistant from the two poles, and in the axial line, then no repulsive effect is or can be observed.

2262. But preserving the point of suspension in the equatorial line, i. e. equidistant from the two poles, and removing it a little on one side or the other of the axial line (2252.), then another effect is brought forth. The bar points as before across the magnetic line of force, but at the same time it recedes from the axial line, increasing its distance from it, and this new position is retained as long as the magnetism continues, and is quitted with its cessation.

2263. Instead of two magnetic poles, a single pole may be used, and that either in a vertical or a horizontal position. The effects are in perfect accordance with those described above; for the bar, when near the pole, is repelled from it in the direction of the line of magnetic force, and at the same time it moves into a position perpendicular to the direction of the magnetic lines passing through it. When the magnet is vertical (2246.) and the bar by its side, this action makes the bar a tangent to the curve of its surface.

2264. To produce these effects, of pointing across the magnetic curves, the form of the heavy glass must be long; a cube, or a fragment approaching roundness in form, will not point, but a long piece will. Two or three rounded pieces or cubes, placed side by side in a paper tray, so as to form an oblong accumulation, will also point.

2265. Portions, however, of any form, are *repelled*: so if two pieces be hung up at once in the axial line, one near each pole, they are repelled by their respective poles, and approach, seeming to attract each other. Or if two pieces be hung up in the equatorial line, one on each side of the axis, then they both recede from the axis, seeming to repel each other.

2266. From the little that has been said, it is evident that the bar presents in its motion a complicated result of the force exerted by the magnetic power over the heavy glass, and that, when cubes or spheres are employed, a much simpler indication of the effect may be obtained. Accordingly, when a cube was thus used with the two poles, the effect was repulsion or recession from either pole, and also recession from the magnetic axis on either side.

2267. So, the indicating particle would move, either along the magnetic curves, or across them; and it would do this either in one direction or the other; the only constant point being, that its tendency was to move from stronger to weaker places of magnetic force.

2268. This appeared much more simply in the case of a single magnetic pole, for then the tendency of the indicating cube or sphere was to move outwards, in the direction of the magnetic lines of force. The appearance was remarkably like a case of weak electric repulsion.

2269. The cause of the pointing of the bar, or any oblong arrangement of the heavy glass, is now evident. It is merely a result of the tendency of the particles to move outwards, or into the positions of weakest magnetic action. The joint ex-

ertion of the action of all the particles brings the mass into the position, which, by experiment, is found to belong to it.

2270. When one or two magnetic poles are active at once, the courses described by particles of heavy glass free to move, form a set of lines or curves, which I may have occasion hereafter to refer to; and as I have called air, glass, water, &c. diamagnetics (2149.), so I will distinguish these lines by the term *diamagnetic curves*, both in relation to, and contradistinction from, the lines called magnetic curves.

2271. When the bar of heavy glass is immersed in water, alcohol, or ether, contained in a vessel between the poles, all the preceding effects occur; the bar points and the cube recedes exactly in the same manner as in air.

2272. The effects equally occur in vessels of wood, stone, earth, copper, lead, silver, or any of those substances which belong to the diamagnetic class (2149.).

2273. I have obtained the same equatorial direction and motions of the heavy glass bar as those just described, but in a very feeble degree, by the use of a good common steel horse-shoe magnet (2157.). I have not obtained them by the use of the helices (2191. 2192.) without the iron cores.

2274. Here therefore we have magnetic repulsion without polarity, i. e. without reference to a particular pole of the magnet, for either pole will repel the substance, and both poles will repel it at once (2262.). The heavy glass, though subject to magnetic action, cannot be considered as magnetic, in the usual acceptation of that term, or as iron, nickel, cobalt, and their compounds. It presents to us, under these circumstances, a magnetic property new to our knowledge; and though the phenomena are very different in their nature and character to those presented by the action of the heavy glass on light (2152.), still they appear to be dependent on, or connected with, the same condition of the glass as made it then effective, and therefore, with those phenomena, prove the reality of this new condition.

¶ iii. *Action of magnets on other substances acting magnetically on light.*

2275. We may now pass from heavy glass to the examination of the other substances, which, when under the power of magnetic or electric forces, are able to affect and rotate a polarized ray (2173.), and may also easily extend the investigation to bodies which, from their irregularity of form, imperfect transparency, or actual opacity, could not be examined by a polarized ray, for here we have no difficulty in the application of the test to all such substances.

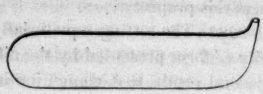
2276. The property of being thus repelled and affected by magnetic poles, was soon found not to be peculiar to heavy glass. Borate of lead, flint-glass, and crown-glass set in the same manner equatorially, and were repelled when near to the poles, though not to the same degree as the heavy glass.

2277. Amongst substances which could not be subjected to the examination by light, phosphorus in the form of a cylinder presented the phenomena very well; I think as powerfully as heavy glass, if not more so. A cylinder of sulphur, and a long

piece of thick India rubber, neither being magnetic after the ordinary fashion, were well directed and repelled.

2278. Crystalline bodies were equally obedient, whether taken from the single or double refracting class (2237,). Prisms of quartz, calcareous spar, nitre and sulphate of soda, all pointed well, and were repelled.

2279. I then proceeded to subject a great number of bodies, taken from every class, to the magnetic forces, and will, to illustrate the variety in the nature of the substances, give a comparatively short list of crystalline, amorphous, liquid and organic bodies below. When the bodies were fluids, I inclosed them in thin glass tubes. Flint-glass points equatorially, but if the tube be of very thin glass, this effect is found to be small when the tube is experimented with alone; afterwards, when it is filled with liquid and examined, the effect is such that there is no fear of mistaking that due to the glass for that of the fluid. The tubes must not be closed with cork, sealing-wax, or any ordinary substance taken at random, for these are generally magnetic (2285.). I have usually so shaped them in the making, and drawn them off at the neck, as to leave the aperture on one side, so that when filled with liquid they required no closing.



2280.

Rock crystal.	Nitric acid.
Sulphate of lime.	Sulphuric acid.
Sulphate of baryta.	Muriatic acid.
Sulphate of soda.	Solutions of various alkaline and earthy salts.
Sulphate of potassa.	
Sulphate of magnesia..	Glass.
Alum.	Litharge.
Muriate of ammonia.	White arsenic.
Chloride of lead.	Iodine.
Chloride of sodium.	Phosphorus.
Nitrate of potassa.	Sulphur.
Nitrate of lead.	Resin.
Carbonate of soda.	Spermaceti.
Iceland spar.	Caffeine.
Acetate of lead.	Cinchonia.
Tartrate of potash and antimony.	Margaric acid.
Tartrate of potash and soda.	Wax from shell-lac.
Tartaric acid.	Sealing-wax.
Citric acid.	Olive-oil.
Water.	Oil of turpentine.
Alcohol.	Jet.
Ether.	Caoutchouc.

Sugar.	Beef, dried.
Starch.	Blood, fresh.
Gum-arabic.	Blood, dried.
Wood.	Leather.
Ivory.	Apple.
Mutton, dried.	Bread.
Beef, fresh.	

2281. It is curious to see such a list as this of bodies presenting on a sudden this remarkable property, and it is strange to find a piece of wood, or beef, or apple, obedient to or repelled by a magnet. If a man could be suspended, with sufficient delicacy, after the manner of DUFAY, and placed in the magnetic field, he would point equatorially; for all the substances of which he is formed, including the blood, possess this property.

2282. The setting equatorially depends upon the form of the body, and the diversity of form presented by the different substances in the list was very great; still the general result, that elongation in one direction was sufficient to make them take up an equatorial position, was established. It was not difficult to perceive that comparatively large masses would point as readily as small ones, because in larger masses more lines of magnetic force would bear in their action on the body, and this was proved to be the case. Neither was it long before it evidently appeared that the form of a plate or a ring was quite as good as that of a cylinder or a prism; and in practice it was found that plates and flat rings of wood, spermaceti, sulphur, &c., if suspended in the right direction, took up the equatorial position very well. If a plate or ring of heavy glass could be floated in water, so as to be free to move in every direction, and were in that condition subject to magnetic forces diminishing in intensity, it would immediately set itself equatorially, and if its centre coincided with the axis of magnetic power, would remain there; but if its centre were out of this line, it would then, perhaps, gradually pass off from this axis in the plane of the equator, and go out from between the poles.

2283. I do not find that division of the substance has any distinct influence on the effects. A piece of Iceland spar was observed, as to the degree of force with which it set equatorially; it was then broken into six or eight fragments, put into a glass tube and tried again; as well as I could ascertain, the effect was the same. By a second operation, the calcareous spar was reduced into coarse particles; afterwards to a coarse powder, and ultimately to a fine powder: being examined as to the equatorial set each time, I could perceive no difference in the effect, until the very last, when I thought there might be a slight diminution of the tendency, but if so, it was almost insensible. I made the same experiment on silica with the same result, of no diminution of power. In reference to this point I may observe, that starch and other bodies in fine powder exhibited the effect very well.

2284. It would require very nice experiments and great care to ascertain the

specific degree of this power of magnetic action possessed by different bodies, and I have made very little progress in that part of the subject. Heavy glass stands above flint-glass, and the latter above plate-glass. Water is beneath all these, and I think alcohol is below water, and ether below alcohol. The borate of lead is I think as high as heavy glass, if not above it, and phosphorus is probably at the head of all the substances just named. I verified the equatorial set of phosphorus between the poles of a common magnet (2273.).

2285. I was much impressed by the fact that blood was not magnetic (2280.), nor any of the specimens tried of red muscular fibre of beef or mutton. This was the more striking, because, as will be seen hereafter, iron is *always* and in almost *all states* magnetic. But in respect to this point it may be observed, that the ordinary magnetic property of matter and this *new property* are in their effects opposed to each other; and that when this property is strong it may overcome a very slight degree of ordinary magnetic force, just as also a certain amount of the magnetic property may oppose and effectually hide the presence of this force (2422.). It is this circumstance which makes it so necessary to be careful in examining the magnetic condition of the bodies in the first instance (2250.). The following list of a few substances, which were found slightly magnetic, will illustrate this point:—Paper, sealing-wax, china ink, Berlin porcelain, silkworm-gut, asbestos, fluor-spar, red lead, vermilion, peroxide of lead, sulphate of zinc, tourmaline, plumbago, shell-lac, charcoal. In some of these cases the magnetism was generally diffused through the body, in other cases it was limited to a particular part.

2286. Having arrived at this point, I may observe, that we can now have no difficulty in admitting that the phenomena abundantly establish the existence of a magnetic property in matter, new to our knowledge. Not the least interesting of the consequences that flow from it, is the manner in which it disposes of the assertion which has sometimes been made, that all bodies are magnetic. Those who hold this view, mean that all bodies are magnetic as iron is, and say that they point between the poles. The new facts give not a mere negative to this statement, but something beyond, namely, an affirmative as to the existence of forces in all ordinary bodies, directly the opposite of those existing in magnetic bodies, for whereas those practically produce attraction, these produce repulsion; those set a body in the axial direction, but these make it take up an equatorial position: and the facts with regard to bodies generally, are exactly the reverse of those which the view quoted indicates.

¶ iv. *Action of magnets on metals generally.*

2287. The metals, as a class, stand amongst bodies having a high and distinct interest in relation both to magnetic and electric forces, and might at first well be expected to present some peculiar phenomena, in relation to the striking property found to be possessed in common by so large a number of substances, so varied in their general characters. As yet no distinction associated with conduction or non-

conduction, transparent or opake, solid or liquid, crystalline or amorphous, whole or broken, has presented itself; whether the metals, distinct as they are as a class, would fall into the great generalization, or whether at last a separation would occur, was to me a point of the highest interest.

2288. That the metals, iron, nickel and cobalt, would stand in a distinct class, appeared almost undoubted; and it will be, I think, for the advantage of the inquiry, that I should consider them in a section apart by themselves. Further, if any other metals appeared to be magnetic, as these are, it would be right and expedient to include them in the same class.

2289. My first point, therefore, was to examine the metals for any indication of ordinary magnetism. Such an examination cannot be carried on by magnets anything short in power of those to be used in the further investigation; and in proof of this point I found many specimens of the metals, which appeared to be perfectly free from magnetism when in the presence of a magnetic needle, or a strong horseshoe magnet (2157.), that yet gave abundant indications when suspended near to one or both poles of the magnets described (2246.).

2290. My test of magnetism was this. If a bar of the metal to be examined, about two inches long, was suspended (2249.) in the magnetic field, and being at first oblique to the axial line, was upon the supervention of the magnetic forces drawn into the axial position instead of being driven into the equatorial line, or remaining in some oblique direction, then I considered it magnetic. Or, if being near one magnetic pole, it was attracted by the pole, instead of being repelled, then I concluded it was magnetic. It is evident that the test is not strict, because, as before pointed out (2285.), a body may have a slight degree of magnetic force, and yet the power of the new property be so great as to neutralize or surpass it. In the first case, it might seem neither to have the one property nor the other; in the second case, it might appear free from magnetism, and possessing the special property in a *small* degree.

2291. I obtained the following metals, so that when examined as above, they did not appear to be magnetic; and in fact if magnetic, were so to an amount so small as not to destroy the results of the other force, or to stop the progress of the inquiry.

Antimony.	Lead.
Bismuth.	Mercury.
Cadmium.	Silver.
Copper.	Tin.
Gold.	Zinc.

2292. The following metals were, and are as yet to me, magnetic, and therefore companions of iron, nickel and cobalt:—

Platinum.	Titanium.
Palladium.	

2293. Whether all these metals are magnetic, in consequence of the presence of a

little iron, nickel, or cobalt in them, or whether any of them are really so of themselves, I do not undertake to decide at present; nor do I mean to say that the metals of the former list are free. I have been much struck by the apparent freedom from iron of almost all the specimens of zinc, copper, antimony and bismuth, which I have examined; and it appears to me very likely that some metals, as arsenic, &c., may have much power in quelling and suppressing the magnetic properties of any portion of iron in them, whilst other metals, as silver or platinum, may have little or no power in this respect.

2294. Resuming the consideration of the influence excited by the magnetic force over those metals which are not magnetic after the manner of iron (2291.), I may state that there are two sets of effects produced which require to be carefully distinguished. One of these depends upon induced magneto-electric currents, and shall be resumed hereafter (2309.). The other includes effects of the same nature as those produced with heavy glass and many other bodies (2276.).

2295. All the non-magnetic metals are subject to the magnetic power, and produce the same general effects as the large class of bodies already described. The force which they then manifest, they possess in different degrees. Antimony and bismuth show it well, and bismuth appears to be especially fitted for the purpose. It excels heavy glass, or borate of lead, and perhaps phosphorus; and a small bar or cylinder of it about two inches long, and from 0·25 to 0·5 of an inch in width, is as well fitted to show the various peculiar phenomena as anything I have yet submitted to examination.

2296. To speak accurately, the bismuth bar which I employed was two inches long, 0·33 of an inch wide, and 0·2 of an inch thick. When this bar was suspended in the magnetic field, between the two poles, and subject to the magnetic force, it pointed freely in the equatorial direction, as the heavy glass did (2253.), and if disturbed from that position, returned *freely* to it. This latter point, though perfectly in accordance with the former phenomena, is in such striking contrast with the phenomena presented by copper and some other of the metals (2309.), as to require particular notice here.

2297. The comparative sensibility of bismuth causes several movements to take place under various circumstances, which being complicated in their nature, require careful analysis and explanation. The chief of these, with their causes, I will proceed to point out.

2298. If the cylinder electro-magnet (2246.) be placed vertically so as to present one pole upwards, that pole will exist in the upper end of an iron cylinder, having a flat horizontal face $2\frac{1}{2}$ inches in diameter. A small indicating sphere (2266.) of bismuth hung over the centre of this face and close to it, does not move by the magnetism. If the ball be carried outwards, half way, for instance, between the centre and the edge, the magnetism makes it move inwards, or towards the axis (prolonged) of the iron cylinder. If carried still further outwards, it still moves inwards under

the influence of the magnetism, and such continues to be the case until it is placed just over the edge of the terminal face of the core, where it has no motion at all (here, by another arrangement of the experiment, it is known to tend in what is at present an upward direction from the core). If carried a little further outwards, the magnetism then makes the bismuth ball tend to go outwards or be repelled, and such continues to be the direction of the force in any further position, or down the side of the end of the core.

2299. In fact, the circular edge formed by the intersection of the end of the core with its sides, is virtually the apex of the magnetic pole, to a body placed like the bismuth ball close to it, and it is because the lines of magnetic force issuing from it diverge as it were, and weaken rapidly in all directions from it, that the ball also tends to pass in all directions either inwards or upwards, or outwards from it, and thus produces the motions described. These same effects do not in fact all occur when the ball, being taken to a greater distance from the iron, is placed in magnetic curves, having generally a simpler direction. In order to remove the effect of the edge, an iron cone was placed on the top of the core, converting the flat end into a cone, and then the indicating ball was urged to move upwards, only when over the apex of the cone, and upward and outwards, as it was more or less on one side of it, being always repelled from the pole in that direction, which transferred it most rapidly from strong to weaker points of magnetic force.

2300. To return to the vertical flat pole: when a horizontal bar of bismuth was suspended concentrically and close to the pole, it could take up a position in any direction relative to the axis of the pole, having at the same time a tendency to move upwards or be repelled from it. If its point of suspension was a little excentric, the bar gradually turned, until it was parallel to a line joining its point of suspension with the prolonged axis of the pole, and the centre of gravity moved inwards. When its point of suspension was just outside the edge of the flat circular terminating face, and the bar formed a certain angle with a radial line joining the axis of the core and the point of suspension, then the movements of the bar were uncertain and wavering. If the angle with the radial line were less than that above, the bar would move into parallelism with the radius and go inwards: if the angle were greater, the bar would move until perpendicular to the radial line and go outwards. If the centre of the bar were still further out than in the last case, or down by the side of the core, the bar would always place itself perpendicular to the radius and go outwards. All these complications of motion are easily resolved into their simple elementary origin, if reference be had to the character of the circular angle bounding the end of the core; to the direction of the magnetic lines of force issuing from it and the other parts of the pole; to the position of the different parts of the bar in these lines; and the ruling principle that each particle tends to go by the nearest course from *strong* to *weaker* points of magnetic force.

2301. The bismuth points well, and is well repelled (2296.) when immersed in water,

alcohol, ether, oil, mercury, &c., and also when inclosed within vessels of earth, glass, copper, lead, &c. (2272.), or when screens of 0·75 or 1 inch in thickness of bismuth, copper, or lead intervene. Even when a bismuth cube (2266.) was placed in an iron vessel $2\frac{1}{2}$ inches in diameter and 0·17 of an inch in thickness, it was well and freely repelled by the magnetic pole.

2302. Whether the bismuth be in one piece or in very fine powder, appears to make no difference in the character or in the degree of its magnetic property (2283.).

2303. I made many experiments with masses and bars of bismuth suspended, or otherwise circumstanced, to ascertain whether two pieces had any mutual action on each other, either of attraction or repulsion, whilst jointly under the influence of the magnetic forces, but I could not find any indication of such mutual action: they appeared to be perfectly indifferent one to another, each tending only to go from stronger to weaker points of magnetic power.

2304. Bismuth, in very fine powder, was sprinkled upon paper, laid over the horizontal circular termination of the vertical pole (2246.). If the paper were tapped, the magnet not being excited, nothing particular occurred; but if the magnetic power were on, then the powder retreated in both directions, inwards and outwards, from a circular line just over the edge of the core, leaving the circle clear, and at the same time showing the tendency of the particles of bismuth in all directions from that line (2299.).

2305. When the pole was terminated by a cone (2246.) and the magnet not in action, paper with bismuth powder sprinkled over it being drawn over the point of the cone, gave no particular result; but when the magnetism was on, such an operation cleared the powder from every point which came over the cone, so that a mark was traced or written out in clear lines running through the powder, and showing every place where the pole had passed.

2306. The bar of bismuth and a bar of antimony was found to set equatorially between the poles of the ordinary horse-shoe magnet.

2307. The following list may serve to give an idea of the apparent order of some metals, as regards their power of producing these new effects, but I cannot be sure that they are perfectly free from the magnetic metals. In addition to that, there are certain other effects produced by the action of magnetism on metals (2309.) which greatly interfere with the results due to the present property.

Bismuth.	Cadmium.
Antimony.	Mercury.
Zinc.	Silver.
Tin.	Copper.

2308. I have a vague impression that the repulsion of bismuth by a magnet has been observed and published several years ago. If so, it will appear that what must

then have been considered as a peculiar and isolated effect, was the consequence of a general property, which is now shown to belong to all matter*.

2309. I now turn to the consideration of some peculiar phenomena which are presented by copper and several of the metals when they are subjected to the action of magnetic forces, and which so tend to mask effects of the kind already described, that if not known to the inquirer they would lead to much confusion and doubt. These I will first describe as to their appearances, and then proceed to consider their origin.

2310. If instead of a bar of bismuth (2296.) a bar of copper of the same size be suspended between the poles (2247.), and magnetic power be developed whilst the bar is in a position oblique to the axial and equatorial lines, the experimenter will perceive the bar to be affected, but this will not be manifest by any tendency of the bar to go to the equatorial line; on the contrary, it will advance towards the axial position as if it were magnetic. It will not, however, continue its course until in that position, but, unlike any effect produced by magnetism, will stop short, and making no vibration beyond or about a given point, will remain there coming at once to a dead rest: and this it will do even though the bar by the effect of torsion or momentum was previously moving with a force that would have caused it to make several gyrations. This effect is in striking contrast with that which occurs when antimony, bismuth, heavy glass, or other such bodies are employed, and it is equally removed from an ordinary magnetic effect.

2311. The position which the bar has taken up it retains with a considerable degree of tenacity, provided the magnetic force be continued. If pushed out of it, it does not return into it, but takes up its new position in the same manner, and holds it with the same stiffness; a push however, which would make the bar spin round several times if no magnetism were present, will now not move it through more than 20° or 30°. This is not the case with bismuth or heavy glass; they vibrate freely in the magnetic field, and always return to the equatorial position.

2312. The position taken up by the bar may be any position. The bar is moved a little at the instant of superinducing the magnetism, but allowing and providing for that, it may be finally fixed in any position required. Even when swinging with considerable power by torsion or momentum, it may be caught and retained in any place the experimenter wishes.

2313. There are two positions in which the bar may be placed at the beginning of

* M. DE LA RIVE has this day referred me to the Bibliothèque Universelle for 1829, tome xl. p. 82, where it will be found that the experiment spoken of above is due to M. LA BAILLIF of Paris. M. LA BAILLIF showed sixteen years ago that both bismuth and antimony repelled the magnetic needle. It is astonishing that such an experiment has remained so long without further results. I rejoice that I am able to insert this reference before the present series of these researches goes to press. Those who read my papers will see here, as on many other occasions, the results of a memory which becomes continually weaker; I only hope that they will be excused, and that omissions and errors of that nature will be considered as involuntary.—M. F. December 30, 1845.

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the experiment, from which the magnetism does not move it, the equatorial and the axial positions. When the bar is nearly midway between these, it is usually most strongly affected by the first action of the magnet, but the position of most effect varies with the form and dimensions of the magnetic poles and of the bar.

2314. If the centre of suspension of the bar be in the axial line, but near to one of the poles, these movements occur well, and are clear and distinct in their direction: if it be in the equatorial line, but on one side of the axial line, they are modified, but in a manner which will easily be understood hereafter.

2315. Having thus stated the effect of the supervention of the magnetic force, let us now remark what occurs at the moment of its cessation; for during its continuance there is no change. If, then, after the magnetism has been sustained for two or three seconds, the electric current be stopped, there is instantly a strong action on the bar, which has the appearance of a revulsion (for the bar returns upon the course which it took for a moment when the electric contact was made), but with such force, that whereas the advance might be perhaps 15° or 20°, the revulsion will cause the bar occasionally to move through two or three revolutions.

2316. Heavy glass or bismuth presents no such phenomena as this.

2317. If, whilst the bar is revolving from revulsion the electric current at the magnet be renewed, the bar instantly stops with the former appearances and results (2310.), and then upon removing the magnetic force is affected again, and, of course, now in a contrary direction to the former revulsion.

2318. When the bar is caught by the magnetic force in the axial or equatorial position, there is no revulsion. When inclined to these positions there is; and the places most powerful in this respect appear to be those most favourable to the first brief advance (2313.). If the bar be in a position at which strong revulsion would occur, and whilst the magnetism is continued be moved by hand into the equatorial or axial position, then on taking off the magnetic force there is no revulsion.

2319. If the continuance of the electric current and consequently of the magnetism be for a moment only, the revulsion is very little, and the shorter the continuance of the magnetic force the less is the revulsion. If the magnetic force be continued for two or three seconds and then interrupted and *instantly* renewed, the bar is loosened and caught again by the power before it sensibly changes its place; and now it may be observed that it does not advance on the *renewal* of the force as it would have done had it been acted on by a first contact in that place (2310.); *i. e.* if the bar be in a certain place inclined to the axial position, the first supervention of the magnetic power causes it to advance towards the axial position; but the bar being in the same place and the magnetic power suspended and *instantly* renewed, the second supervention of force does not move the bar as the first did.

2320. When the copper bar is immersed in water, alcohol, or even mercury, the same effects take place as in the air, but the movements are, of course, not to the same extent.

2321. When plates of copper or bismuth, an inch in thickness, intervene between the poles and the copper bar, the same results occur.

2322. If one magnetic pole only be employed the effects occur near it as well as before, provided that pole have a face large in proportion to the bar, as the end of the iron core (2246.): but if the pole be pointed by the use of the conical termination, or if the bar be opposite the edge of the end of the core, then they become greatly enfeebled or disappear altogether; and only the general fact of repulsion remains (2295.).

2323. The peculiar effects which have just been described are perhaps more strikingly shown if the bar of copper be suspended perpendicularly, and then hung opposite and near to the large face of a single magnetic pole, or the pole being placed vertically, as described (2246. 2263.), anywhere near to its side. The bar, it will be remembered, is two inches in length by 0·33 of an inch in width, and 0·2 of an inch in thickness, and as it now will revolve on an axis parallel to its length, the two smaller dimensions are those which are free to move into new positions. In this case the establishment of the magnetic force causes the bar to turn a little in accordance with the effects before described, and the removal of the magnetic force causes a revulsion, which sends the bar spinning round on its axis several times. But at any moment the bar can again be caught and held in a position as before. The tendency on making contact at the battery is to place the longest moving dimension, *i. e.* the width of the bar, parallel to the line joining the centre of action of the magnet and the bar.

2324. The bar, as before (2311.), is extremely sluggish and as if immersed in a dense fluid, as respects rotation on its own axis; but this sluggishness does not affect the bar as a whole, for any pendulum vibration it has continues unaffected. It is very curious to see the bar, jointly vibrating from its point of suspension (2249.) and rotating on its axis, when first affected by the magnetic force, for instantly the latter motion ceases, but the former goes on with undiminished power.

2325. The same effect of sluggishness occurs with a cube or a globe of copper as with the bar, but the phenomena of the first turn and the revulsion cease (2310. 2315.).

2326. The bars of bismuth and heavy glass present no appearance of this kind. The peculiar phenomena produced by copper are as distinct from the actions of these substances as they are from ordinary magnetic actions.

2327. Endeavouring to explain the cause of these effects, it appears to me that they depend upon the excellent conducting power of copper for electric currents, the *gradual* acquisition and loss of magnetic power by the iron core of the electro-magnet, and the production of those induced currents of magneto-electricity which I described in the First Series of these Experimental Researches (55. 109.).

2328. The obstruction to motion on its own axis, when the bar is subjected to the magnetic forces, belongs equally to the form of a sphere or a cube. It belongs to these bodies, however, only when their axes of rotation are perpendicular or oblique

to the lines of magnetic force, and not when they are parallel to it; for the horizontal bar, or the vertical bar, or the cube or sphere, rotate with perfect facility when they are suspended *above* the vertical pole (2246.), the rotation and vibration being then equally free, and the same as the corresponding movements of bismuth or heavy glass. The obstruction is at a maximum when the axis of rotation is perpendicular to the lines of magnetic force, and when the bar or cube, &c. is near to the magnet.

2329. Without going much into the particular circumstances, I may say that the effect is fully explained by the electric currents induced in the copper mass. By reference to the Second Series of these Researches (160.)*, it will be seen that when a globe, subject to the action of lines of magnetic force, is revolving on an axis perpendicular to these lines, an electric current runs round it in a plane parallel to the axis of rotation and to the magnetic lines, producing consequently a magnetic axis in the globe, at right angles to the magnetic curves of the inducing magnet. The magnetic poles of this axis therefore are in that direction which, in conjunction with the chief magnetic pole, tends to draw the globe back against the direction in which it is revolving. Thus, if a piece of copper be revolving before a north magnetic pole, so that the parts nearest the pole move towards the right-hand, then the right-hand side of that copper will have a south magnetic state, and the left-hand side a north magnetic state; and these states will tend to counteract the motion of the copper towards the right-hand: or if it revolve in the contrary direction, then the right-hand side will have a south magnetic state, and the left-hand side a north magnetic state. Whichever way, therefore, the copper tends to revolve on its own axis, the instant it moves, a power is evolved in such a direction as tends to stop its motion and bring it to rest. Being at rest in reference to this direction of motion, then there is no residual or other effect which tends to disturb it, and it remains still.

2330. If the whole mass be moving parallel to itself, and be small in comparison with the face of the magnetic pole opposite to which it is placed, then, though it pass through the magnetic lines of force, and consequently have a tendency to the formation of magneto-electric currents within it, yet as all parts move with equal velocity and in the same direction through similar magnetic lines of force, the tendency to the formation of a current is the same in every part, and there is no actual production of current, and consequently nothing occurs which can in any way interfere with its freedom of motion. Hence the reason that though the rotation of the bar or cube (2324. 2328.) upon its own axis is stopped, its vibration as a pendulum is not affected.

2331. That neither the one nor the other motion is affected when the bar or cube is over the vertical pole (2328.), is simply because in both cases (with the given dimensions of the pole and the moving metal) the lines of particles through which the induced currents tend to move are parallel throughout the whole mass; and

* Philosophical Transactions, 1832, p. 168.

therefore, as there is no part by which the return of the current can be carried on, no current can be formed.

2332. Before proceeding to the explanation of the other phenomena, it will be necessary to point out the fact generally understood and acknowledged, I believe, that time is required for the development of magnetism in an iron core by a current of electricity; and also for its fall back again when the current is stopped. One effect of the gradual rise in power was referred to in the last series of these Researches (2170.). This time is probably longer with iron not well annealed than with very good and perfectly annealed iron. The last portions of magnetism which a given current can develope in a certain core of iron, are also apparently acquired more slowly than the first portions; and these portions (or the condition of iron to which they are due) also appear to be lost more slowly than the other portions of the power. If electric contact be made for an instant only, the magnetism developed by the current disappears as instantly on the breaking of the current, as it appeared on its formation; but if contact be continued for three or four seconds, breaking the contact is by no means accompanied by a disappearance of the magnetism with equal rapidity.

2333. In order to trace the peculiar effect of the copper, and its cause, let us consider the condition of the horizontal bar (2310. 2313.) when in the equatorial position, between the two magnetic poles, or before a single pole; the point of suspension being in a line with the axis of the pole and its exciting wire helix. On sending an electric current through the helix, both it and the magnet it produces will conduce to the formation of currents in the copper bar in the contrary direction. This is shown from my former researches (26.), and may be proved, by placing a small or large wire helix-shaped (if it be desired) in the form of the bar, and carrying away the currents produced in it, by wires to a galvanometer at a distance. Such currents being produced in the copper, only continue whilst the magnetism of the core is rising and then cease (18. 39.), but *whilst* they continue, they give a virtual magnetic polarity to that face of the copper bar which is opposite to a certain pole, the polarity being the same in kind as the pole it faces. Thus on the side of the bar facing the north pole of the magnet, a north polarity will be developed; and on that side facing the south pole, a south polarity will be generated.

2334. It is easy to see that if the copper during this time were opposite only one pole, or being between two poles, were nearer to one than the other, this effect would cause its repulsion. Still, it cannot account for the whole amount of the repulsion observed alike with copper as with bismuth (2295.), because the currents are of but momentary duration, and the repulsion due to them would cease with them. They do, however, cause a brief repulsive effort, to which is chiefly due the first part of the peculiar effect.

2335. For if the copper bar, instead of being parallel to the face of the magnetic pole, and therefore at right angles to the resultant of magnetic force, be inclined,

forming, for instance, an angle of 45° with the face, then the induced currents will move generally in a plane corresponding more or less to that angle, nearly as they do in the examining helix (2333.), if it be inclined in the same manner. This throws the polar axis of the bar of copper on one side, so that the north polarity is not directly opposed to the north pole of the inducing magnet, and hence the action both of this and the other magnetic pole upon the two polarities of the copper will be to send it further round, or to place it edgeways to the poles, or with its breadth parallel to the magnetic resultant passing through it (2323.): the bar therefore receives an impulse, and the angle of it nearest to the magnet appears to be pulled up towards the magnet. This action of course stops the instant the magnetism of the helix core ceases to rise, and then the motion due to this cause ceases, and the copper is simply subject to the action before described (2295.). At the same time that this twist or small portion of a turn round the point of suspension occurs, the centre of gravity of the whole mass is repelled, and thus I believe all the actions up to this condition of things is accounted for.

2336. Then comes the *revulsion* which occurs upon the cessation of the electric current, and the falling of the magnetism in the core. According to the law of magneto-electric induction, the disappearance of the magnetic force will induce brief currents in the copper bar (28.), but in the contrary direction to those induced in the first instance; and therefore the virtual magnetic pole belonging to the copper for the moment, which is nearest the north end of the electro-magnet, will be a south pole; and that which is furthest from the same pole of the magnet will be a north pole. Hence will arise an exertion of force on the bar tending to turn it round its centre of suspension in the contrary direction to that which occurred before, and hence the apparent revulsion; for the angle nearest the magnetic pole will recede from it, the broad face (2323.) or length (2315.) of the bar will come round and face towards the magnet, and an action the reverse in every respect of the first action will take place, except that whereas the motion was then only a few degrees, now it may extend to two or three revolutions.

2337. The cause of this difference is very obvious. In the first instance, the bar of copper was moving under influences powerfully tending to retard and stop it (2329.); in the second case these influences are gone, and the bar revolves freely with a force proportionate to the power exerted by the magnet upon the currents induced by its own action.

2338. Even when the copper is of such form as not to give the oblique resultant of magnetic action from the currents induced in it, when, for instance, it is a cube or a sphere, still the effect of the action described above is evident (2325.). When a plate of copper about three-fourths of an inch in thickness, and weighing two pounds, was sustained upon some loose blocks of wood and placed about 0·1 of an inch from the face of the magnetic pole, it was repelled and held off a certain distance upon the making and continuing of electric contact at the battery; and when the battery cur-

rent was stopped, it returned towards the pole; but the return was much more powerful than that due to gravity alone (as was ascertained by an experiment), the plate being at that moment actually *attracted*, as well as tending by gravitation towards the magnet, so that it gave a strong tap against it.

2339. Such is, I believe, the explanation of the peculiar phenomena presented by copper in the magnetic field; and the reason why they appear with this metal and not with bismuth or heavy glass, is almost certainly to be found in its high electro-conducting power, which permits the formation of currents in it by inductive forces, that cannot produce the same in a corresponding degree in bismuth, and of course not at all in heavy glass.

2340. Any ordinary magnetism due to metals by virtue of their inherent power, or the presence of small portions of the magnetic metals in them, must oppose the development of the results I have been describing; and hence metals not of absolute purity cannot be compared with each other in this respect. I have, nevertheless, observed the same phenomena in other metals; and as far as regards the sluggishness of rotatory motion, traced it even into bismuth. The following are the metals which have presented the phenomena in a greater or smaller degree:—

Copper.	Mercury.
Silver.	Platinum.
Gold.	Palladium.
Zinc.	Lead.
Cadmium.	Antimony.
Tin.	Bismuth.

2341. The accordance of these phenomena with the beautiful discovery of ARAGO*, with the results of the experiments of HERSCHEL and BABBAGE†, and with my own former inquiries (81.)‡, are very evident. Whether the effect obtained by AMPÈRE, with his copper cylinder and a helix§, was of this nature, I cannot judge, inasmuch as the circumstances of the experiment and the energy of the apparatus are not sufficiently stated; but it probably may have been.

2342. As, because of other duties, three or four weeks may elapse before I shall be able to complete the verification of certain experiments and conclusions, I submit at once these results to the attention of the Royal Society, and will shortly embody the account of the action of magnets on magnetic metals, their action on gases and vapours, and the general considerations in another series of these Researches.

Royal Institution,
Nov. 27, 1845.

* Annales de Chimie, xxvii. 363; xxviii. 325; xxxii. 213. I am very glad to refer here to the Comptes Rendus of June 9, 1845, where it appears that it was M. ARAGO who first obtained his peculiar results by the use of electro- as well as common magnets.

† Philosophical Transactions, 1825, p. 467.

‡ Ibid. 1832, p. 146.

§ Bibliothèque Universelle, xxi. p. 48.

III. *Experimental Researches in Electricity.—Twenty-first Series.*

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§ 27. *On new magnetic actions, and on the magnetic condition of all matter—continued.* ¶ v. *Action of magnets on the magnetic metals and their compounds.* ¶ vi. *Action of magnets on air and gases.* ¶ vii. *General considerations.*

¶ v. *Action of magnets on the magnetic metals and their compounds.*

2343. THE magnetic characters of iron, nickel and cobalt, are well known; and also the fact that at certain temperatures they lose their usual property and become, to ordinary test and observation, non-magnetic; then entering into the list of diamagnetic bodies and acting in like manner with them. Closer investigation, however, has shown me that they are still very different to other bodies, and that though inactive when hot, on common magnets or to common tests, they are not so absolutely, but retain a certain amount of magnetic power whatever their temperature; and also that this power is the same in character with that which they ordinarily possess.

2344. A piece of iron wire, about one inch long and 0·05 of an inch in diameter, being thoroughly cleaned, was suspended at the middle by a fine platinum wire connected with the suspending thread (2249.) so as to swing between the poles of the electro-magnet. The heat of a spirit-lamp was applied to it, and it soon acquired a temperature which rendered it quite insensible to the presence of a good ordinary magnet, however closely it was approached to the heated iron. The temperature of the iron was then raised considerably higher by adjustment of the flame, and the electro-magnet thrown into action. Immediately the hot iron became magnetic and pointed between the poles. The power was feeble, and in this respect the state of the iron was in striking contrast with that which it had when cold; but in character the force was precisely the same.

2345. The iron was then allowed to fall in temperature slowly so that its assumption of the higher magnetic condition might be observed. The intensity of the force did not appear to increase until the temperature arrived near a certain point, and

then as the heat continued to diminish, the iron rapidly, but not instantaneously, acquired its high magnetic power; at which time it could not be kept from the magnet, but flew to it, bending the suspending wire and trembling as it were with magnetic energy as it adhered by one end to the core.

2346. A small bar of nickel was submitted to an experimental examination in the same manner. This metal, as I have shown*, loses its magnetism as respects ordinary tests at a heat below that of boiling oil, and hence it is very well fitted to show whether the magnetic metals can have their power entirely removed by heat or not; and also, whether the disappearance of the whole or greater portion of their power is sudden or gradual. The smallness of the mass to be experimented on assisted much in the determination of the latter point. Upon being heated the nickel soon became indifferent to ordinary magnets; but however high the temperature, still it pointed to and was attracted by the electro-magnet. The power was very feeble, but certain. It was scarcely enough to sustain the weight of the nickel by the magnetic action alone; but was abundantly evident when the metal was supported as described (2344.).

2347. On carefully lowering the temperature of the nickel, it was again found that the transition from one degree of magnetic force to the other was progressive, and not instantaneous. With iron it is difficult to preserve all the parts, either in heating or cooling, so nearly at the same temperature as to be sure that it is not the union of hotter and colder portions which gives the appearance of an intermediate degree of magnetism; but with nickel that is not so difficult, for the progression is more gradual, so that when in cooling the power began to increase, the cooling might be continued some time before the full degree of power came on; at any time in that period the temperature might be slightly raised, and though the power would then diminish a little, it could yet be retained at a degree stronger than the weakest. In fact it was easy to *keep* the nickel at many of the intermediate degrees of power, and thus to remove all doubt of the progressive assumption of the full degree of force.

2348. I have expressed an opinion, founded on the different temperatures at which the magnetic metals appeared to lose their peculiar power†, that all the metals would probably have the same character of magnetism if their temperature could be lowered sufficiently. The facts just described appear to me entirely against such an opinion. The metals which are magnetic retain a portion of their power after the great change has been effected, or in what might be called their diamagnetic state; but the other metals, such as bismuth, tin, &c., present no trace of this power, and therefore are not in the condition of the heated iron, nickel, or cobalt; for in fact whilst these point axially and are attracted, the others point equatorially and are repelled. I therefore hope to be allowed to withdraw the view I then put forth.

2349. I next proceeded to examine the peroxides of iron, and in accordance with

* Philosophical Magazine, 1836, vol. viii. p. 179. † Ibid. 177; ibid. 1839, vol. xiv. p. 161.

the observations of M. Becquerel* and others, found them all, both natural and artificial, possessed of magnetic power at common temperatures. I heated them in tubes but found them still magnetic, suffering *no* diminution of the force by such temperature as I could apply to them.

2350. Different specimens of the oxide of nickel were found to present the same phenomena. They were magnetic both when hot and cold; and that heat should cause no change in this respect is the more striking, because the hot oxide had a temperature given to it far higher than that necessary to produce the great magnetic change in the metal itself (2346.).

2351. The oxide of cobalt also was magnetic, and equally magnetic whether hot or cold. Glass coloured blue by cobalt is magnetic in consequence of the presence of the oxide of that metal, and is so whether hot or cold. In all these cases the degree of power retained was very small compared to that of the pure metal.

2352. Proceeding to the *salts* of iron, I found them magnetic. Clean crystals of the proto-sulphate of iron were attracted and pointed axially very well; so also did the dry salt. As I proceeded I found that every salt and compound containing iron in the basic part was magnetic. To enumerate the different substances subjected to trial would be tedious, the following are selected as illustrations of the variety in kind:—

Protochloride.	Protophosphate.
Perchloride.	Perphosphate.
Iodide.	Nitrate.
Protosulphate.	Carbonate.
Persulphate.	Prussian blue.

2353. Amongst native compounds—

Bog iron ore.	Yellow sulphuret of iron.
Hæmatite.	Arsenical pyrites.
Chromate of iron.	Copper pyrites, and many others were magnetic.

2354. Green bottle-glass is comparatively very magnetic from the iron it contains, and cannot be used as tubes to hold other substances. Crown-glass is magnetic from the same cause. Flint-glass is not magnetic, but points equatorially.

2355. Crystals of the yellow ferro-prussiate of potassa were not magnetic, but were repelled and set equatorially; and such was the case also with red ferro-prussiate.

2356. According to my hopes, even the solutions of the ferruginous salts, whether in water or alcohol, were magnetic. A tube filled with a clear solution of proto- or persulphate of iron, or proto- or perchloride, or tincture of muriate of iron, was attracted by the poles, and pointed very well between them in the axial direction.

2357. These solutions supply a very important means of advancing magnetical investigation, for they present us with the power of making a magnet, which is at the same time liquid, transparent, and within certain limits, adjustible to any degree

* Annales de Chimie, 1827, vol. xxxvi. p. 337. Comptes Rendus, 1845, vol. xx. p. 1708.

of strength. Hence the power of examining a magnet optically. Hence also, the capability of placing magnetic portions of matter one within another, and so observing dynamic and other phenomena within magnetic media. In fact, not only may these substances be placed as magnets in the magnetic field, but the field generally may be filled with them, and then other bodies and other magnets examined as to their joint or separate actions in it (2361., &c.).

2358. In reference to the salts of *nickel* and *cobalt*, pure crystals of the sulphate of nickel were found to be well magnetic, and also pure crystals of sulphate of cobalt. Solutions of the sulphate of nickel, the chloride of nickel, and the chloride of cobalt, were also magnetic. That I might be perfectly safe in these conclusions I applied to Mr. ASKIN of Birmingham, whose power of separating nickel and cobalt from each other and other metals is well known, as also the scale upon which he carries on these operations, and he favoured me with a solution of chloride of nickel, and another of chloride of cobalt perfectly pure, both of which proved to be well magnetic between the poles of my magnet.

2359. Heat applied to any of these magnetic solutions did not diminish or affect their power.

2360. These results with the salts of the magnetic metals conjoin with those before quoted, as tending to show that the non-magnetic metals could not by any change of temperature be rendered magnetic (2398.), but as a class are distinct from iron, nickel, and cobalt; for none of the compounds of the non-magnetic metals show, as yet, any indication of ordinary magnetic force, whereas in respect of these three substances all their compounds possess it.

2361. In illustration of the power which the iron and other similar solutions give in the investigation of magnetic phenomena (2357.), as well as in reference to the general conclusions to be drawn from all the facts described in this paper, I will proceed to describe certain anticipated results which were obtained by the employment of these solutions in the magnetic field.

2362. A clear solution of the proto-sulphate of iron was prepared, in which one ounce of the liquid contained seventy-four grains of the hydrated crystals; a second solution was prepared containing one volume of the former and three volumes of water; a third solution was made of one volume of the stronger solution and fifteen volumes of water. These solutions I will distinguish as Nos. 1, 2, and 3; the proportions of crystals of sulphate of iron in them were respectively as 16, 4, and 1 per cent. nearly. These numbers may, therefore, be taken as representing (generally only (2423.)) the strength of the magnetic part of the liquids.

2363. Tubes like that before described (2279.) were prepared and filled respectively with these solutions and then hermetically sealed, as little air as possible being left in them. Glasses of the solutions were also prepared, large enough to allow the tubes to move freely in them, and yet of such size and shape as would permit of their being placed between the magnetic poles. In this manner the action of the

magnetic forces upon the matter in the tubes could be examined and observed, both when the tubes were in diamagnetic media, as air, water, alcohol, &c., and also in magnetic media, either stronger or weaker in magnetic force than the substances in the tubes.

2364. When these tubes were suspended in air between the poles, they all pointed axially or magnetically, as was to be expected; and with forces apparently proportionate to the strengths of the solutions. When they were immersed in alcohol or water, they also pointed in the same direction; the strongest solution very well, and also the second, but the weakest solution was feeble in its action though very distinct in its character (2422.).

2365. When the tubes, immersed in the different ferruginous solutions, were acted upon, the results were very interesting. The tube No. 1 (the strongest magnetically), when in solution No. 1, had no tendency, under the influence of the magnetic power, to any particular position, but remained wherever it was placed. Being placed in solution No. 2, it pointed well axially, and in solution No. 3 it took the same direction, but with still more power.

2366. The tube No. 2, when in the solution No. 1, pointed equatorially, *i. e.* as heavy glass, bismuth, or a diamagnetic body generally, in air. In solution No. 2 it was indifferent, not pointing either way; and in solution No. 3 it pointed axially, or as a magnetic body. The tube No. 3 containing the weakest solution, pointed equatorially in solutions No. 1 and 2, and not at all in solution No. 3.

2367. Several other ferruginous solutions varying in strength were prepared, and, as a general and constant result, it was found that any tube pointed axially if the solution in it was stronger than the surrounding solution, and equatorially if the tube solution was the weaker of the two.

2368. The tubes were now suspended vertically, so that being in the different solutions they could be brought near to one of the magnetic poles, and employed in place of the indicating cube or sphere of bismuth, or heavy glass (2266.). The constant result was, that when the tube contained a stronger solution than that which surrounded it, it was attracted to the pole, but when its solution was the weaker of the two it was repelled. The latter phenomena were as to appearance in every respect the same as those presented in the repulsion of heavy glass, bismuth, or any other diamagnetic body in air.

2369. Having described these phenomena, I will defer their further consideration until I arrive at the last division of this paper, and proceed to certain results more especially belonging to the present part of these Researches.

2370. As the magnetic metals, iron, nickel and cobalt, present in their compounds substances also distinguished by the possession of magnetic properties (2360.), so it appeared very probable that other metals, of whose magnetic character doubts were entertained, because of the possible presence of iron in the specimens experimented with, might in this way have their magnetic character tested; for it seemed likely, from analogy, that every metal well magnetic *per se*, would be magnetic in its com-

pounds; and, judging from the character of the great class of diamagnetic bodies (2275.), that no magnetic compounds would be obtained of a metal not magnetic of itself. Accordingly I proceeded to apply this kind of test to the combinations of many of the metals, and obtained the following results:—

2371. *Titanium.*—Wollaston has described the magnetic effects of crystals of titanium, expressing at the same time a belief that they are due to iron*. I took a specimen of the oxide of titanium, which I believe to be perfectly free from iron, and inclosing it in a tube (2279.), subjected it to the action of the electro-magnet (2246. 2247.). It proved to be freely magnetic. Another specimen obtained from Mr. Johnson, and believed by him to be perfectly free from iron, was also magnetic. Hence I conclude that titanium is truly a magnetic metal.

2372. *Manganese.*—Berthier, as far as I am aware, first announced that this metal was magnetic at very low temperatures†. On submitting specimens of the various oxides, which were considered as pure, to the magnetic force, they were all found to be magnetic, especially the protoxide. So were the following compounds of manganese in the pure, dry, or crystallized state:—chloride, sulphate, ammonio-sulphate, phosphate, carbonate, borate; and also the chloride, nitrate, sulphate, and ammonio-sulphate when in solution. A specimen of the ammonio-sulphate was rendered alkaline by the addition of a little carbonate of ammonia boiled and then carefully crystallized thrice; after that the crystals and solution of the purified salt were perfectly and well magnetic. I have no doubt, therefore, that manganese is a magnetic metal, as Berthier said. If any opinion may be drawn concerning the magnetic force of the metal from the degree of magnetism of the compounds, I should expect that manganese possesses considerable power of this kind when at a sufficiently low temperature‡.

2373. *Cerium.*—I am not aware that cerium has as yet been classed with the magnetic metals. Having made experiments with the hydrated protoxide, the carbonate, and the chloride of this metal, and also with the double sulphate of the oxide and potassa prepared with great care, I found them all magnetic; and those that are soluble are magnetic in the state of solution. Hence, as the compounds are undoubtedly magnetic, there is every reason to believe that cerium also is a magnetic metal (2370.).

2374. *Chromium.*—The magnetic phenomena of chromium compounds are very interesting. Portions of the chromate and the bichromate of potassa were purified by three careful crystallizations each; part of the bichromate was heated in a platinum crucible, until the second equivalent of chromic acid was converted into the crystallized oxide, and this being washed out and dried was found to be well magnetic. So were all the other specimens of oxide of chromium which were examined.

A specimen of Warrington's chromic acid was found to be very feebly magnetic.

* Philosophical Transactions, 1823, p. 400.

† Traité des Essais par la Voie Sêche, tome i. p. 532. Philosophical Magazine, 1845, vol. xxvii. p. 2.

‡ Philosophical Magazine, 1845, vol. xxvii. p. 2.

2375. Chromate of lead, when subjected to the magnet, pointed equatorially and was repelled. Such was the case also with crystals of the chromate of potassa. Crystals of the bichromate, however, did not act thus; for if in any way affected they were in the least degree magnetic, showing the influence of the increased proportion of chromic acid. Solutions of either salt pointed well equatorially and were repelled; thus showing the diamagnetic influence of the water present (2422.).

2376. As just stated, a solution of the bichromate contained in a tube, pointed equatorially and was repelled; but if the same solution had a little alcohol added to it, and also some pure muriatic or sulphuric acid, and were then heated for a few minutes to reduce the chromic acid to the state of oxide or chloride, then, on being returned to the tube and subjected to the magnet, it was found strongly magnetic.

2377. I think it has before been said that chromium is a magnetic metal; as these results have been obtained with its pure compounds, there is no longer any doubt on my mind that such is the case.

2378. *Lead.*—The compounds of lead point equatorially and are repelled. The substances tried were the chloride, iodide, sulphuret, nitrate, sulphate, phosphate, carbonate, protoxide fused, and the acetate. A portion of very carefully crystallized nitrate being dissolved was precipitated by pure zinc, and the lead obtained washed with dilute nitric acid, to remove subsalts. Such lead was free from magnetism, and therefore the metal ranks in the diamagnetic class, both directly and by its compounds. Lead usually appears to be magnetic, and it is not very easy to obtain the metal in the pure diamagnetic state.

2379. *Platinum.*—I have, as yet, found no wrought specimens of this metal free from magnetism, not even those prepared by Dr. Wollaston himself, and left with the Royal Society. Specimens of the purest platinum obtained from Mr. Johnson were also found to be slightly magnetic.

2380. Clean platinum foil and cuttings were dissolved in pure nitro-muriatic acid, and the solution evaporated to dryness. Both the solution and the dry chloride pointed equatorially and were repelled by the magnet. A part of the chloride being dissolved and rendered acid, was precipitated by an acid solution of muriate of ammonia, and the ammonio-chloride of platinum washed and dried: it also, at the magnet, pointed equatorially and was repelled. A portion of this ammonio-chloride, decomposed in a flint-glass tube by heat, gave spongy platinum, which being pressed together into a cake, pointed *axially* and was attracted at the side of the magnetic pole, being magnetic.

2381. At present I believe that platinum is as a metal magnetic, though very slightly so; and that in the compounds, the change of state and the presence of other substances having the diamagnetic character, are sufficient to cover this property and make the whole compound diamagnetic (2422.).

2382. *Palladium.*—All the palladium in the possession of the Royal Society, prepared by Dr. Wollaston, amounting to ten ingots and rolled plates, is magnetic.

Specimens of the metal from Mr. JOHNSON, considered as pure, were also slightly magnetic. The chloride, the ammonio-bichloride, and the cyanuret of palladium, pointed equatorially and were repelled by the magnet. The same cyanuret, reduced by heat either in open platinum vessels or in close glass tubes, gave palladium possessing a feeble degree of magnetic property. Some of WOLLASTON'S palladium was dissolved in pure nitromuriatic acid, and the solution slowly acted upon by pure zinc, free from iron, and not magnetic. Five successive portions of the precipitated metal were collected, and *all* were *magnetic*. Ammonio-bichloride of palladium was prepared from the same solution by pure acid muriate of ammonia, and digested in nitromuriatic acid. The salt itself was repelled, being diamagnetic; but when reduced by heat in glass tubes, or in Berlin capsules, the palladium obtained was magnetic. From the result of all the experiments, I believe the metal to be feebly but truly magnetic.

2383. *Arsenic.*—This metal required very particular examination, and even when carefully sublimed twice or thrice in succession, presented appearances which sometimes made me class it with the magnetic, and at other times with the diamagnetic bodies. On the whole, I incline to believe that it belongs to the latter series of substances, being only in a very small degree removed from the zero or medium point. Pure white arsenic points freely in an equatorial direction, and is repelled by a magnetic pole.

2384. In reference to the pointing of short bars between magnetic poles exposing large flat faces, I ought to observe, that such bars will sometimes point axially and seem to be magnetic when they do not belong to that class, and are repelled by a single pole. The cause of this effect has been already given (2298. 2299.), and is obviated by the use of poles having wedge-shaped or conical terminations.

2385. *Osmium.*—Osmic acid from Mr. JOHNSON, in fine transparent crystals, was clearly diamagnetic, being repelled. Specimens of the metal and of the protoxide were both slightly magnetic. The protoxide had been obtained by the action of alcohol on a solution of osmic acid which had twice been distilled with water, and the metal was believed to be perfectly free from other substances. Probably, therefore, osmium belongs to the magnetic class.

2386. *Iridium.*—Mr. JOHNSON supplied me with several preparations of iridium. The oxide, chloride, and ammonio-chloride were magnetic; and so was a sample of the metal. One specimen of the metal, which seemed to be very pure, was scarcely at all magnetic; and on the whole, I incline to believe that iridium does not stand in the magnetic class.

2387. *Rhodium.*—A well-fused specimen of this metal, prepared by Dr. WOLLASTON, was magnetic; but crystals of the chloride and the sodio-chloride of rhodium prepared by the same philosopher, and others also from Mr. JOHNSON, were not magnetic, but pointed well equatorially. I conclude, therefore, that the metal is probably not magnetic, or if magnetic, is but little removed from the zero point.

2388. *Uranium.*—Peroxide of this metal was obtained not magnetic; protoxide very slightly magnetic: I have set the metal for the present in the diamagnetic class.

2389. *Tungsten.*—The oxide of this metal, and also the acid, were submitted to examination, and found to point well equatorially. The acid was distinctly repelled by a single magnetic pole; the oxide appeared nearly neutral. Hence I have, for the present, considered tungsten as a diamagnetic metal.

2390. *Silver* is not magnetic (2291.), nor its compounds.

2391. *Antimony* is not magnetic (2291.), nor its compounds.

2392. *Bismuth* is not magnetic (2291.), nor its compounds.

Having tried many of the compounds of each of these three metals, I thought it well to record the accordance existing between them and their metallic bases (2370.).

2393. *Sodium.*—A fine large globule, equal to half a cubic inch in size, was well repelled, and is therefore diamagnetic.

2394. *Magnesium.*—None of the compounds or salts of this base are magnetic.

2395.

Calcium.	Sodium.
Strontium.	Potassium.
Barium.	Ammonia.

None of the compounds or salts of these substances are magnetic.

2396. From the characters, therefore, of the compounds, as well as from direct evidence in respect of some of the metals, it would appear that, besides iron, nickel, and cobalt, the following are also magnetic; namely, titanium, manganese, cerium, chromium, palladium, platinum. It is, however, very probable that there may be metals possessing distinct magnetic power, yet in so slight a degree as, like platinum and palladium, not to exhibit in their compounds any sensible trace of it. Such may be the case with tungsten, uranium, rhodium, &c.

2397. I have heated several of the diamagnetic metals, even up to their fusing-points, but have not been able to observe any change, either in the character or degree of their magnetic relations.

2398. Perhaps the cooling of some of the metals, whose compounds, like those of iron, nickel and cobalt, are magnetic, might develope in them a much higher degree of force than any which they have as yet been known to possess. Manganese, chromium, cerium, titanium, are metals of much interest in this point of view. Osmium, iridium, rhodium and uranium, ought to be subjected with them to the same trial.

2399. The following is an attempt to arrange some of the metals in order, as respects their relation to magnetic force. The 0° or medium point is supposed to be the condition of a metal or substance indifferent to the magnetic force as respects attraction or repulsion in air or space. The further substances are placed from this point, the more distinctive are they as regards their attraction or repulsion by the magnet. Nevertheless this order may, very probably, be found inaccurate by more careful observation.

Magnetic.	Diamagnetic.
	Bismuth.
	Antimony.
	Zinc.
	Tin.
	Cadmium.
	Sodium.
Iron.	Mercury.
Nickel.	Lead.
Cobalt.	Silver.
Manganese.	Copper.
Chromium.	Gold.
Cerium.	Arsenic.
Titanium.	Uranium.
Palladium.	Rhodium.
Platinum.	Iridium.
Osmium.	Tungsten.
0°.	

¶ vi. *Action of magnets on air and gases.*

2400. It was impossible to advance in an experimental investigation of the kind now described, without having the mind impressed with various theoretical views of the mode of action of the bodies producing the phenomena. In the passing consideration of these views, the apparently middle condition which *air* held between magnetic and diamagnetic substances was of the utmost interest, and led to many experiments upon its probable influence, which I will now proceed briefly to describe.

2401. A thin flint-glass tube, in which common air was hermetically enclosed, was placed between the magnetic poles (2249.) surrounded by air, and the effect of the magnetic force observed upon it. There was a very feeble tendency of the tube to an equatorial position, due to the substance of the tube in which the air was enclosed.

2402. The air was then withdrawn from around the tube more or less, and at last up to the highest amount which a good air-pump would effect; but whatever the degree of rarefaction, the tube of air still seemed to be affected exactly in the same manner as if surrounded by air of its own density.

2403. I then surrounded the air-tube with hydrogen and carbonic acid in succession; but in both these, and in each of them at different degrees of rarefaction, the tube of air remained as indifferent as before.

2404. Hence there appears to be no sensible distinction between dense or rare air; or, as far as these experiments go, between one gas or vapour and another.

2405. As it did not seem at all unlikely that the equatorial and axial set of bodies,

or their repulsions and attractions, might depend upon converse actions of the media by which they were surrounded (2361.), so I proceeded to examine what would occur with diamagnetic substances, when the air or gas which surrounded them was changed in its density or nature, or what would happen to air itself when surrounded by these substances.

2406. The air-tube (2401.) was suspended horizontally in water (being retained below the surface by a cube of bismuth attached to it, just beneath the point of suspension, which therefore could have no power of giving it direction); it was then subjected to the magnetic forces, and immediately pointed well in an axial direction, or as a magnet would have done. Being brought near to one pole it moved, on the supervention of the magnetic force, appearing as if *attracted* after the manner of a magnetic body; and this continued as long as the magnetic force was sustained in action.

2407. The air-tube was in like manner subjected to the action of the magnetic force, when surrounded by alcohol, and also by oil of turpentine, with precisely the same results as in water. In all these cases the action of air in the fluids was precisely the same as the action of a magnetic body in air. The air-tube was subjected to the action of the magnet even when under the surface of mercury, and here also it pointed axially.

2408. In order to extend the experimental relations of air and gases, I proceeded to place substances of the diamagnetic class in them. Thus, the bar of heavy glass (2253.) was suspended in a jar of air, and then the air about it more or less rarefied, but, as before, in the case of the air-tube (2402.), alterations of this kind produced no effect. Whether the bar were in air at the ordinary pressure, or as rare as the pump could render it, it still pointed equatorially, and apparently always with the same degree of force.

2409. The bar of bismuth (2296.) was suspended in the jar, and the same alteration in the density of the air made as before; but this caused no difference in the action of the bismuth, either in kind or degree. Carbonic acid and hydrogen gases were then introduced in succession into the jar, and these also were employed in different degrees of rarefaction, but the results were the same; no change took place in the action on the bismuth.

2410. A bismuth cube was suspended in air and gases at ordinary pressure, and also rarefied as much as could be, and under these circumstances it was brought near the magnetic pole and its repulsion observed; its action was in all these cases precisely the same as in the atmosphere.

2411. The perpendicular copper bar (2323.) was suspended near the magnetic pole *in vacuo*, but its set, sluggish movements and revulsion, were just the same as before in air (2324.).

2412. The following preparations in tubes (2401.), namely, a vacuum, air, hydrogen, carbonic acid gas, sulphurous acid gas, and vapour of ether, were surrounded

by water, and then subjected to the magnetic force; they all pointed axially, and, as far as I could perceive, with equal force. Being placed in alcohol the same effect occurred.

2413. The same preparations being surrounded by air, or by carbonic acid gas, all set equatorially.

2414. The axial position of the tubes in the liquid (2412.) depends, doubtless, upon the relation of the contents of the tube to the surrounding medium; for as far as the matter of the tube is concerned, it alone would have tended to give the equatorial position. In the following succeeding experiments (2413.), where the tubes of gases were in surrounding gases, the equatorial position is due to this effect of the glass of the tube; and that it should produce its constant feeble effect, undisturbed by all the variations of the gases and vapours, is a proof how like and how indifferent these are one to the other.

2415. I suspended a tube of liquid sulphurous acid in gaseous sulphurous acid; when under the magnetic influence, the liquid pointed well equatorially. I surrounded liquid nitrous acid by gaseous nitrous acid; the liquid pointed well equatorially. I placed liquid ether in the vapour of ether; the former pointed equatorially. Upon suspending the tube of vapour of ether in liquid ether, the vapour pointed axially.

2416. In every kind of trial, therefore, and in every form of experiment, the gases and vapours still occupy a medium position between the magnetic and the diamagnetic classes. Further, whatever the chemical or other properties of the substances, however different in their specific gravity, or however varied in their own degree of rarefaction, they all become alike in their magnetic relation, and apparently equivalent to a perfect vacuum. Bodies which are very marked as diamagnetic substances, immediately lose all traces of this character when they become vaporous (2415.). It would be exceedingly interesting to know whether a body from the magnetic class, as chloride of iron, would undergo the same change.

¶ vii. *General considerations.*

2417. Such are the facts which, in addition to those presented by the phenomena of light, establish a magnetic action or condition of matter new to our knowledge. Under this action, an elongated portion of such matter usually (2253. 2384.) places itself at right angles to the lines of magnetic force; this result may be resolved into the simpler one of repulsion of the matter by either magnetic pole. The set of the elongated portion, or the repulsion of the whole mass, continues as long as the magnetic force is sustained, and ceases with its cessation.

2418. By the exertion of this new condition of force, the body moved may pass either *along* the magnetic lines or *across* them; and it may move along or across them in either or any direction. So that two portions of matter, simultaneously subject to this power, may be made to approach each other as if they were mutually

attracted, or recede as if mutually repelled. All the phenomena resolve themselves into this, that a portion of such matter, when under magnetic action, tends to move from stronger to weaker places or points of force. When the substance is surrounded by lines of magnetic force of equal power on all sides, it does not tend to move, and is then in marked contradistinction with a linear current of electricity under the same circumstances.

2419. This condition and effect is new, not *only* as it respects the exertion of power by a magnet over bodies previously supposed to be indifferent to its influence, but is *new* as a magnetic action, presenting us with a second mode in which the magnetic power can exert its influence. These two modes are in the same general antithetical relation to each other as positive and negative in electricity, or as northness and southness in polarity, or as the lines of electric and magnetic force in magneto-electricity; and the diamagnetic phenomena are the more important, because they extend largely, and in a new direction, that character of duality which the magnetic force already, in a certain degree, was known to possess.

2420. All matter appears to be subject to the magnetic force as universally as it is to the gravitating, the electric and the chemical or cohesive forces; for that which is not affected by it in the manner of ordinary magnetic action, is affected in the manner I have now described; the matter possessing for the time the solid or fluid state. Hence substances appear to arrange themselves into two great divisions, the magnetic, and that which I have called the diamagnetic classes; and between these classes the contrast is so great and direct, though varying in degree, that where a substance from the one class will be attracted, a body from the other will be repelled; and where a bar of the one will assume a certain position, a bar of the other will acquire a position at right angles to it.

2421. As yet I have not found a single solid or fluid body, not being a mixture, that is perfectly neutral in relation to the two lists; *i. e.* that is neither attracted nor repelled in air. It would probably be important to the consideration of magnetic action, to know if there were any natural simple substance possessing this condition in the solid or fluid state. Of compound or mixed bodies there may be many; and as it may be important to the advancement of experimental investigation, I will describe the principles on which such a substance was prepared when required for use as a circumambient medium.

2422. It is manifest that the properties of magnetic and diamagnetic bodies are in opposition as respects their dynamic effects; and, therefore, that by a due mixture of bodies from each class, a substance having any intermediate degree of the property of either may be obtained. Protosulphate of iron belongs to the magnetic, and water to the diamagnetic class; and using these substances, I found it easy to make a solution which was neither attracted nor repelled, nor pointed when in air. Such a solution pointed axially when surrounded by water. If made somewhat weaker in respect of the iron, it would point axially in water but equatorially in air; and it

could be made to pass more and more into the magnetic or the diamagnetic class by the addition of more sulphate of iron or more water.

2423. Thus a *fluid* medium was obtained, which, practically, as far as I could perceive, had every magnetic character and effect of a gas, and even of a vacuum; and as we possess both magnetic and diamagnetic glass (2354.), it is evidently possible to prepare a *solid* substance possessing the same neutral magnetic character.

2424. The endeavour to form a general list of substances in the present imperfect state of our knowledge would be very premature: the one below is given therefore only for the purpose of conveying an idea of the singular association under which bodies come in relation to magnetic force, and for the purpose of general reference hereafter:—

Iron.
Nickel.
Cobalt.
Manganese.
Palladium.
Crown-glass.
Platinum.
Osmium.
0° Air and vacuum.
Arsenic.
Ether.
Alcohol.
Gold.
Water.
Mercury.
Flint-glass.
Tin.
Heavy glass.
Antimony.
Phosphorus.
Bismuth.

2425. It is very interesting to observe that metals are the substances which stand at the extremities of the list, being of all bodies those which are most powerfully opposed to each other in their magnetic condition. It is also a very remarkable circumstance that these differences and departures from the medium condition, are in the metals at the two extremes, iron and bismuth, associated with a small conducting power for electricity. At the same time the *contrast* between these metals, as to their fibrous and granular state, their malleable and brittle character, will press upon the mind whilst contemplating the possible condition of their molecules when subjected to magnetic force.

2426. In reference to the metals, as well as the diamagnetics not of that class (2286.), it is satisfactory to have such an answer to the opinion that all bodies are magnetic as iron, as does not consist in a mere negation of that which is affirmed, but in proofs that they are in a different and opposed state, and are able to counteract a very considerable degree of magnetic force (2448.).

2427. As already stated, the magnetic force is so strikingly distinct in its action upon bodies of the magnetic and the diamagnetic class, that when it causes the attraction of the one it produces the repulsion of the other; and this we cannot help referring, in some way, to an action upon the molecules or the mass of the substances acted upon, by which they are thrown into different conditions and affected accordingly. In that point of view it is very striking to compare the results with those which are presented to us by a polarized ray, especially as then a remarkable difference comes into view; for if transparent bodies be taken from the two classes, as for instance, heavy glass or water from the diamagnetic, and a piece of green glass or a solution of green vitriol from the magnetic class, then a given line of magnetic force will cause the repulsion of one and the attraction of the other; but this same line of force which thus affects the particles so differently, affects the polarized ray when passing through them precisely in the *same* manner in both cases; for the two bodies cause its rotation in the *same* direction (2160. 2199. 2224.).

2428. This consideration becomes even more important when we connect it with the diamagnetic and the optical properties of bodies which rotate a polarized ray. Thus the iron solution and a piece of quartz, having the power to rotate a ray, point by the influence of the *same* line of magnetic force, the one axially and the other equatorially; but the rotation which is impressed on a ray of light by these two bodies, as far as they are under the influence of the same magnetic force, is the *same* for both. Further, this rotation is quite independent of, and quite unlike that of the quartz in a most important point; for the quartz by itself can only rotate the ray in one direction, but under the influence of the magnetic force it can rotate it both to the right and left, according to the course of the ray (2231. 2232.). Or, if two pieces of quartz (or two tubes of oil of turpentine) be taken which can rotate the ray *different* ways, the further rotative force manifested by them when under the dominion of the magnetism is always the *same* way; and the direction of that way may be made either to the right or left in either crystal of quartz. All this time the *contrast* between the quartz as a diamagnetic, and the solution of iron as a magnetic body remains undisturbed. Certain considerations regarding the character of a ray, arising from these contrasts, press strongly on my mind, which, when I have had time to submit them to further experiment, I hope to present to the Society.

2429. Theoretically, an explanation of the movements of the diamagnetic bodies, and all the dynamic phenomena consequent upon the actions of magnets on them, might be offered in the supposition that magnetic induction caused in them a contrary state to that which it produced in magnetic matter; *i. e.* that if a particle of

each kind of matter were placed in the magnetic field both would become magnetic, and each would have its axis parallel to the resultant of magnetic force passing through it; but the particle of magnetic matter would have its north and south poles opposite, or facing towards the contrary poles of the inducing magnet, whereas with the diamagnetic particles the reverse would be the case; and hence would result approximation in the one substance, recession in the other.

2430. Upon AMPÈRE's theory, this view would be equivalent to the supposition, that as currents are induced in iron and magnetics parallel to those existing in the inducing magnet or battery wire; so in bismuth, heavy glass and diamagnetic bodies, the currents induced are in the contrary direction. This would make the currents in diamagnetics the same in direction as those which are induced in diamagnetic conductors at the *commencement* of the inducing current; and those in magnetic bodies the same as those produced at the *cessation* of the same inducing current. No difficulty would occur as respects non-conducting magnetic and diamagnetic substances, because the hypothetical currents are supposed to exist not in the mass, but round the particles of the matter.

2431. As far as experiment yet bears upon such a notion, we may observe, that the known inductive effects upon masses of magnetic and diamagnetic metals *are the same*. If a straight rod of iron be carried across magnetic lines of force, or if it, or a helix of iron rods or wire, be held near a magnet, as the power in it rises electric currents are induced, which move through the bars or helix in certain determinate directions (38. 114., &c.). If a bar or a helix of bismuth be employed under the same circumstances the currents are again induced, and precisely in the same direction as in the iron, so that here no difference occurs in the direction of the induced current, and not very much in its force, nothing like so much indeed as between the current induced in either of these metals and a metal taken from near the neutral point (2399.). Still there is this difference remaining between the conditions of the experiment and the hypothetical case; that in the former the induction is manifested by currents in the masses, whilst in the latter, *i. e.* in the special magnetic and diamagnetic effects, the currents, if they exist, are probably about the particles of the matter.

2432. The magnetic relation of aëriform bodies is exceedingly remarkable. That oxygen or nitrogen gas should stand in a position intermediate between the magnetic and diamagnetic classes; that it should occupy the place which *no* solid or liquid element can take; that it should show no change in its relations by rarefaction to any possible degree, or even when the space it occupies passes into a vacuum; that it should be the same magnetically with any other gas or vapour; that it should not take its place at one end but in the very middle of the great series of bodies; and that all gases or vapours should be alike, from the rarest state of hydrogen to the densest state of carbonic acid, sulphurous acid, or ether vapour, are points so striking,

as to persuade one at once that air must have a great and perhaps an active part to play in the physical and terrestrial arrangement of magnetic forces.

2433. At one time I looked to air and gases as the bodies which, allowing attenuation of their substance without addition, would permit of the observation of corresponding variations in their magnetic properties; but now all such power by rarefaction appears to be taken away; and though it is easy to prepare a liquid medium which shall act with other bodies as air does (2422.), still it is not truly in the same relation to them; neither does it allow of dilution, for to add water or any such substance is to add to the diamagnetic power of the liquid; and, if it were possible to convert it into vapour and so dilute it by heat, it would pass into the class of gases and be magnetically undistinguishable from the rest.

2434. It is also very remarkable to observe the apparent disappearance of magnetic condition and effect when bodies assume the vaporous or gaseous state, comparing it at the same time with the similar relation to light; for as yet no gas or vapour has been made to show any magnetic influence over the polarized ray, even by the use of powers far more than enough to manifest such action freely in liquid and solid bodies.

2435. Whether the negative results obtained by the use of gases and vapours depend upon the smaller quantity of matter in a given volume, or whether they are direct consequences of the altered physical condition of the substance, is a point of very great importance to the theory of magnetism. I have imagined, in elucidation of the subject, an experiment with one of M. Cagniard de la Tour's ether tubes, but expect to find great difficulty in carrying it into execution, chiefly on account of the strength, and therefore the mass of the tube necessary to resist the expansion of the imprisoned heated ether.

2436. The remarkable condition of air and its relation to bodies taken from the magnetic and the diamagnetic classes, causes it to point equatorially in the former and axially in the latter. Or, if the experiment presents its results under the form of attraction and repulsion, the air moves as if repelled in a magnetic medium and attracted in a medium from the diamagnetic class. Hence it seems as if the air were magnetic when compared with diamagnetic bodies, and of the latter class when compared to magnetic bodies.

2437. This result I have considered as explained by the assumption that bismuth and its congeners are absolutely repelled by the magnetic poles, and would, if there were nothing else concerned in the phenomenon than the magnet and the bismuth, be equally repelled. So also with the iron and its similars, the attraction has been assumed as a direct result of the mutual action of them and the magnets; further, these actions have been admitted as sufficient to account for the pointing of the air both axially and equatorially, as also for its apparent attraction and repulsion; the effect in these cases being considered as due to the travelling of the air to those positions which the magnetic or diamagnetic bodies tended to leave.

2438. The effects with air are, however, in these results precisely the same as those which were obtained with the solutions of iron of various strength (2365.), where *all* the bodies belonged to the magnetic class, and where the effect was evidently due to the greater or smaller degree of magnetic power possessed by the solutions. A weak solution in a stronger pointed equatorially and was repelled like a diamagnetic, not because it did not tend by attraction to an axial position, but because it tended to that position with less force than the matter around it; so the question will enter the mind, whether the diamagnetics, when in air, are repelled and tend to the equatorial position for any other reason, than that the air is more magnetic than they are, and tends to occupy the axial space. It is easy to perceive that if all bodies were magnetic in different degrees, forming one great series from end to end, with air in the middle of the series, the effects would take place as they do actually occur. Any body from the middle part of the series would point equatorially in the bodies above it and axially in those beneath it; for the matter which, like bismuth, goes from a strong to a weak point of action, may do so only because that substance, which is already at the place of weak action, tends to come to the place where the action is strong; just as in electrical induction the bodies best fitted to carry on the force are drawn into the shortest line of action. And so air in water, or even under mercury, is, or appears to be, drawn towards the magnetic pole.

2439. But if this were the true view, and air had such power amongst other bodies as to stand in the midst of them, then one would be led to expect that rarefaction of the air would affect its place, rendering it, perhaps, more diamagnetic, or at all events altering its situation in the list. If such were the case, bodies that set equatorially in it in one state of density, would, as it varied, change their position, and at last set axially: but this they do not do; and whether the rarefied air be compared with the magnetic or the diamagnetic class, or even with dense air, it keeps its place.

2440. Such a view also would make mere space magnetic, and precisely to the same degree as air and gases. Now though it may very well be, that space, air and gases, have the same general relation to magnetic force, it seems to me a great additional assumption to suppose that they are all absolutely magnetic, and in the midst of a series of bodies, rather than to suppose that they are in a normal or zero state. For the present, therefore, I incline to the former view, and consequently to the opinion that diamagnetics have a specific action antithetically distinct from ordinary magnetic action, and have thus presented us with a magnetic property new to our knowledge.

2441. The amount of this power in diamagnetic substances seems to be very small, when estimated by its dynamic effect, but the motion which it can generate is perhaps not the most striking measure of its force; and it is probable that when its nature is more intimately known to us, other effects produced by it and other indicators and measurers of its powers, than those so imperfectly made known in this paper, will come to our knowledge; and perhaps even new classes of phenomena will serve

to make it manifest and indicate its operation. It is very striking to observe the feeble condition of a helix when alone, and the astonishing force which, in giving and receiving, it manifests by association with a piece of soft iron. So also here we may hope for some analogous development of this element of power, so new as yet to our experience. It cannot for a moment be supposed, that, being given to natural bodies, it is either superfluous or insufficient, or unnecessary. It doubtless has its appointed office, and that, one which relates to the whole mass of the globe; and it is probably because of its relation to the whole earth, that its amount is necessarily so small (so to speak) in the portions of matter which we handle and subject to experiment. And small as it is, how vastly greater is this force, even in dynamic results, than the mighty power of gravitation, for instance, which binds the whole universe together, when manifested by masses of matter of equal magnitude!

2442. With a full conviction that the uses of this power in nature will be developed hereafter, and that they will prove, as all other natural results of force do, not merely important but essential, I will venture a few hasty observations.

2443. Matter cannot thus be affected by the magnetic forces without being itself concerned in the phenomenon, and exerting in turn a due amount of influence upon the magnetic force. It requires mere observation to be satisfied that when a magnet is acting upon a piece of soft iron, the iron itself, by the condition which its particles assume, carries on the force to distant points, giving it direction and concentration in a manner most striking. So also here the condition which the particles of intervening diamagnetics acquire, may be the very condition which carries on and causes the transfer of force through them. In former papers (1161, &c.)* I proposed a theory of electrical induction founded on the action of contiguous particles, with which I am now even more content than at the time of its proposition: and I then ventured to suggest that probably the lateral action of electrical currents which is equivalent to electrodynamic or *magnetic* action, was also conveyed onwards in a similar manner (1663. 1710. 1729. 1735.). At that time I could discover no peculiar condition of the intervening or diamagnetic matter; but now that we are able to distinguish such an action, so *like* in its nature in bodies so *unlike* in theirs, and by that so like in character to the manner in which the magnetic force pervades all kinds of bodies, being at the same time as universal in its presence as it is in its action; now that diamagnetics are shown not to be indifferent bodies, I feel still more confidence in repeating the same suggestion, and asking whether it may not be by the action of the contiguous or next succeeding particles that the magnetic force is carried onwards, and whether the peculiar condition acquired by diamagnetics when subject to magnetic action, is not that condition by which such propagation of the force is affected?

2444. Whichever view we take of solid and liquid substances, whether as forming two lists, or one great magnetic class (2424. 2437.), it will not, as far as I can perceive, affect the question. They are all subject to the influence of the magnetic lines of

* Philosophical Transactions, 1838, Part I.

force passing through them, and the virtual difference in property and character between any two substances taken from different places in the list (2424.) will be the same; for it is the differential relation of the two which governs their mutual effects.

2445. It is that group which includes air, gases, vapours, and even a vacuum which presents any difficulty to the mind; but here there is such a wonderful change in the physical constitution of the bodies, and such high powers in some respects are retained by them, whilst others seem to vanish, that we might almost expect some peculiar condition to be assumed in regard to a power so universal as the magnetic force. Electric induction being an action through distance, is varied enough amongst solid and liquid bodies; but, when it comes to be exerted in air or gases, where it most manifestly exists, it is alike in amount in all (1292.); neither does it vary in degree in air however rare or dense it may be (1284.). Now magnetic action may be considered as a mere function of electric force, and if it should be found to correspond with the latter in this particular relation to air, gases, &c., it would not excite in my mind any surprise.

2446. In reference to the manner in which it is possible for electric force, either static or dynamic, to be transferred from particle to particle when they are at a distance from each other, or across a vacuum, I have nothing to add to what I have said before (1614, &c.). The supposition that such can take place, can present nothing startling to the mind of those who have endeavoured to comprehend the radiation and the conduction of heat under one principle of action.

2447. When we consider the magnetic condition of the earth as a whole, without reference to its possible relation to the sun, and reflect upon the enormous amount of diamagnetic matters which, to our knowledge, forms its crust; and when we remember that magnetic curves of a certain amount of force and universal in their presence, are passing through these matters and keeping them constantly in that state of tension, and therefore of action, which I hope successfully to have developed, we cannot doubt but that some great purpose of utility to the system, and us its inhabitants, is thereby fulfilled, which now we shall have the pleasure of searching out.

2448. Of the substances which compose the crust of the earth, by far the greater portion belongs to the diamagnetic class; and though ferruginous and other magnetic matters, being more energetic in their action, are consequently more striking in their phenomena, we should be hasty in assuming that therefore they overrule entirely the effect of the former bodies. As regards the ocean, lakes, rivers, and the atmosphere, they will exert their peculiar effect almost uninfluenced by any magnetic matter in them; and as respects the rocks and mountains, their diamagnetic influence is perhaps greater than might be anticipated. I mentioned that, by adjusting water and a salt of iron together, I obtained a solution inactive in air (2422.); that is, by a due association of the forces of a body from each class, water and a salt of iron, the magnetic force of the latter was entirely counteracted by the diamagnetic force of the

former, and the mixture was neither attracted nor repelled. To produce this effect, it required that more than 48·6 grains of crystallized protosulphate of iron should be added to ten cubic inches of water (for these proportions gave a solution which still set equatorially), a quantity so large, that I was greatly astonished on observing the power of the water to overcome it. It is not therefore at all unlikely that many of the masses which form the crust of this our globe may have an excess of diamagnetic power and act accordingly.

2449. Though the general disposition of the magnetic curves which permeate and surround our globe resemble those of a very short magnet, and therefore give lines of force rapidly diverging in their general form, yet the magnitude of the system prevents us from observing any diminution of their power within small limits; so that probably any attempt on the surface of the earth to observe the tendency of matter to pass from stronger to weaker places of action would fail. Theoretically, however, and at first sight, I think a pound of bismuth or of water, estimated at the equator, where the magnetic needle does not dip, ought to weigh less when taken into latitudes where the dip is considerable; whilst a pound of iron, nickel, or cobalt, ought, under the same change of circumstances, to weigh more. If such should really prove to be the case, then a ball of iron and another of bismuth, attached to the ends of a delicate balance beam, should cause that beam to take different inclinations on different parts of the surface of the earth; and it does not seem quite impossible that an instrument to measure one of the conditions of terrestrial magnetic force might be constructed on such a principle.

2450. If one might speculate upon the effect of the whole system of curves upon very large masses, and these masses were in plates or rings, then they would, according to analogy with the magnetic field, place themselves equatorially. If Saturn were a magnet as the earth is, and his ring composed of diamagnetic substances, the tendency of the magnetic forces would be to place it in the position which it actually has.

2451. It is a curious sight to see a piece of wood, or of beef, or an apple, or a bottle of water repelled by a magnet, or taking the leaf of a tree and hanging it up between the poles, to observe it take an equatorial position. Whether any similar effects occur in nature among the myriads of forms which, upon all parts of its surface, are surrounded by air, and are subject to the action of lines of magnetic force, is a question which can only be answered by future observation.

2452. Of the interior of the earth we know nothing, but there are many reasons for believing that it is of a high temperature. On this supposition I have recently remarked, that at a certain distance from the surface downwards, magnetic substances must be entirely destitute, either of the power of retaining magnetism, or becoming magnetic by induction from currents in the crust or otherwise*. This is evidently an error; that the iron, &c. can retain no magnetic condition of itself, is

* Philosophical Magazine, 1845, vol. xxvii. p. 3.

very probably true, but that the magnetic metals and all their compounds retain a certain degree of power to become magnetic by induction, whatever their temperature, has now been proved (2344, &c.). The deep magnetic contents of the earth, therefore, though they probably do not constitute of themselves a central magnet, are just in the condition to act as a very soft iron core to the currents around them, or other inducing actions, and very likely are highly important in this respect. What the effect of the diamagnetic part may be under the influence of such inductive forces, we are not prepared to state; but as far as I have been able to observe, such bodies have not their power diminished by heat (2397.).

2453. If the sun have anything to do with the magnetism of the globe, then it is probable that part of its effect is due to the action of the light that comes to us from it; and in that expectation the air seems most strikingly placed round our sphere, investing it with a transparent diamagnetic, which therefore is permeable to his rays, and at the same time moving with great velocity across them. Such conditions seem to suggest the possibility of magnetism being there generated; but I shall do better to refrain from giving expression to these vague thoughts (though they will press in upon the mind), and first submitting them to rigid investigation by experiment, if they prove worthy, then present them hereafter to the Royal Society.

Royal Institution,
Dec. 22, 1845.

Feb. 2, 1846.—I add the following notes and references to these Researches:—

Brugmans first observed the repulsion of bismuth by a magnet in 1778. *Antonii Brugmans Magnetismus seu de affinitatibus magneticis observationes magneticæ.* Lugd. Batav. 1778, § 41.

M. Le Baillif on the Repulsion of a Magnet by Bismuth and Antimony, Bulletin Universel, 1827, vol. vii. p. 371; vol. viii. pp. 87. 91. 94.

Saigey on the Magnetism of certain natural combinations of Iron, and on the mutual repulsions of Bodies in general. Ibid. 1828, vol. ix. pp. 89. 167. 239.

Seebeck on the Magnetic Polarity of different Metals, Alloys and Oxides. Ibid. 1828, vol. ix. p. 175.